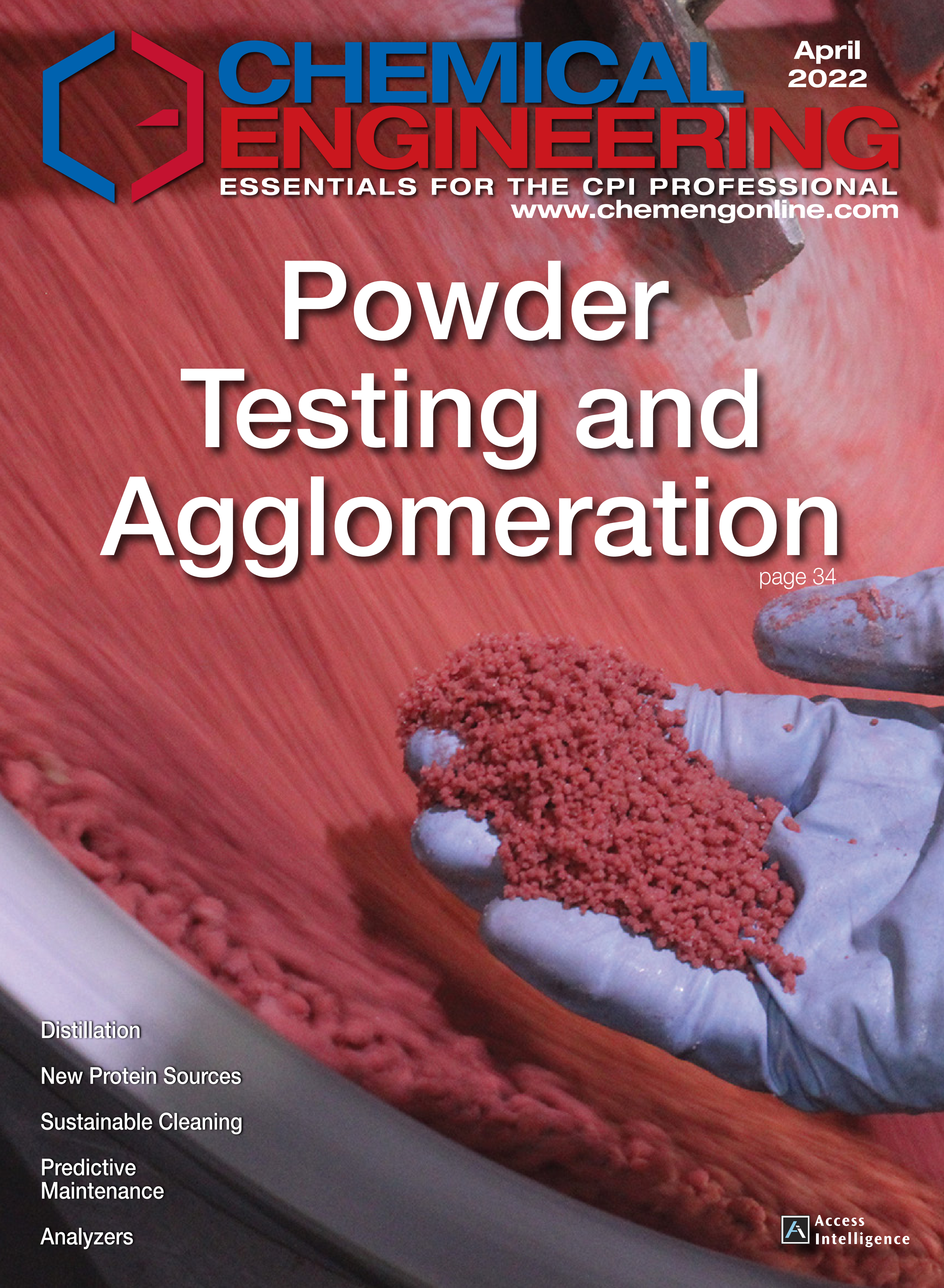

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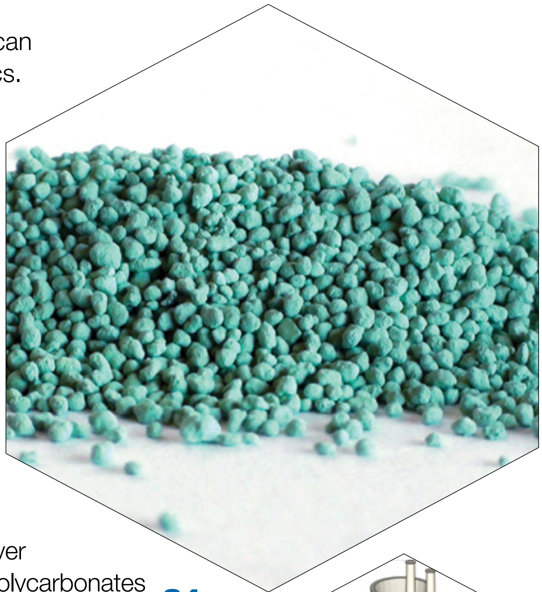

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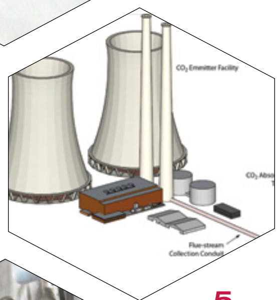

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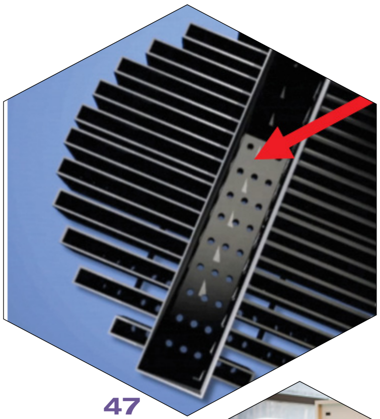

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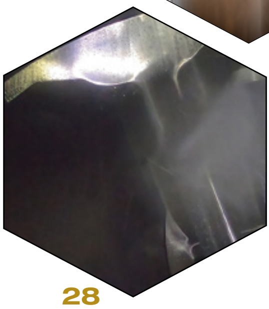

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Editor's Page

Climate change and food security

A new, extensive report examining the impacts of climate change around the world warns that the effects of climate change are more widespread with further-reaching consequences than previously thought. Compiled by 270 authors from 67 countries, the report [*1*] was released on February 28 by the Intergovernmental Panel on Climate Change (IPCC; www.ipcc.ch), the United Nations (UN) body for assessing the science related to climate change. With the world focused on the immediate global concerns of the devastating war in Europe and the pandemic that has not yet loosened its grip around the globe, news of the stark warnings outlined in the IPCC report may have been somewhat overshadowed.

Losses, damage and displacement of people due to extreme weather events, including droughts, wildfires, heatwaves, cyclones and floods; stresses to our food supply, water scarcity and an increase in disease are some of the devastating effects of climate change cited by the report. Along with a warning that extreme events are projected to increase in magnitude and frequency with irreversible changes, the report calls for urgent global action to avert the worst-case scenarios. Stressing the importance of immediate action, IPCC Working Group II Co-Chair Hans-Otto Pörtner said "The scientific evidence is unequivocal: climate change is a threat to human wellbeing and the health of the planet. Any further delay in concerted global action will miss a brief and rapidly closing window to secure a liveable future." The next report by the IPCC, focusing on mitigation of climate change, is expected to be released in April of this year.

Food insecurity

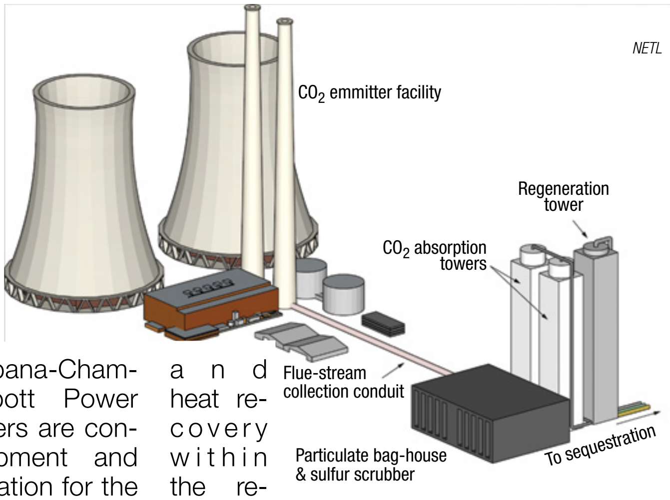
The projected impacts of climate change as outlined in Chapter 5 of the IPCC report include that some regions will no longer be suitable for crops or livestock, outdoor workers and livestock will be more exposed to extreme weather conditions, food safety will be impacted by higher temperatures and humidity, and fisheries and aquaculture productivity will decline. There are, of course, other factors in addition to climate change heightening concerns about global food security, such as increasing population, economics and effects of the pandemic.

Alternate sources of protein for food are being pursued to help address food shortage concerns. One alternate protein source for human consumption mentioned in the IPCC report and also recommended as an area where chemical engineers can have an impact in the report "New Directions for Chemical Engineering" by the National Academies of Sciences, Engineering and Medicine (Washington, D.C.; www.nationalacademies.org) is laboratory-grown meat. Also called "clean meat" or "cultivated meat," this protein source is produced by growing animal cells in a controlled environment. According to McKinsey & Company [*2*], the cultivated-meat market could reach $25 billion by 2030, depending on consumer acceptance and price. Approval of consumption of the laboratory-grown meat by regulatory authorities is also a factor. Interest in this field is growing quickly, with pilot plants already in operation. For more, see our Newsfront in this issue, "A Taste of Foods to Come," pp. 13–16. ■

Dorothy Lozowski, Editorial Director

1. IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate, Cambridge University Press. In Press. https://report.ipcc.ch
2. McKinsey & Company, "Cultivated meat: Out of the lab into the frying pan," June 16, 2021. www.mckinsey.com

Mixed-salt processes target lower-cost CO_2 capture



A mixed-salt process (MSP) designed to reduce the costs and increase the energy efficiency of removing carbon dioxide from post-combustion fluegas is advancing in two related projects. In the first, a 10-MW engineering-scale demonstration plant for the MSP is under construction at the University of Illinois' (Urbana-Champaign; www.illinois.edu) Abbott Power Plant. In the second, researchers are conducting bench-scale development and testing of a new solvent formulation for the MSP that is designed to further improve the process economics.

MSP emerged from earlier work by SRI International (Menlo Park, Calif.; www.sri.com) that investigated chilled ammonia as a solvent for CO_2 capture (*Chem. Eng.*, July 2013, p. 11).

The MSP, which was licensed to Baker Hughes (Houston; www.bakerhughes.com) in 2021, uses a non-degradable solvent based on inexpensive K_2CO_3 and NH_3 solutions to remove CO_2 from power plant exhaust gas. The National Energy Technology Laboratory (NETL; Morgantown, W.Va.; www.netl.doe.gov), which is providing cost-shared funding for the two projects, notes that in the MSP chemistry, NH_3 plays a dual role as a catalyst and as an absorbent, due to its high mobility and reactivity with CO_2.

"By operating absorbers near ambient temperature, solvent-chilling energy requirements are reduced, as is water usage and ammonia loss, resulting in reduced operational costs," according to NETL technology manager Andrew Jones. Also, high-pressure stripping and heat recovery within the regenerator reduces CO_2 compression requirements, which lowers both capital and operational costs, project leaders state.

The MSP demonstration plant, slated to be completed in 2024, aims to test the process with real-world fluegas for long time periods, while demonstrating the process efficiencies and gathering information for a techno-economic analysis.

Meanwhile, SRI is conducting large bench-scale testing on an advanced version of the MSP (A-MSP). In this project, the tertiary amine methyl diethanolamine (MDEA), traditionally used for treating acid gas, is added to the solvent formulation to increase the CO_2 loading and reduce parasitic energy loss. "The key advantage of the A-MSP design is operation of the regenerator at low temperature and high pressure, eliminating water stripping and thus generating a greater than 99%-pure dry CO_2 stream," says Jones. This results in cost reductions for solvent regeneration and CO_2 compression and allows the removal of the expensive first CO_2 compression stage.

Edited by:
Gerald Ondrey

ENZYMES IN A CAGE

Researchers at the Karlsruhe Institute of Technology (KIT; Germany; www.kit.edu) have embedded enzymes into metal-organic frameworks (MOFs), and demonstrated for the first time that stabilization by these frameworks is sufficient for use of the enzymes in a continuous reactor. The enzymes are stabilized in both aqueous and organic solvents.

Using an enzyme-MOF flow reactor, the researchers found that the stability of the immobilized enzyme was about 30 times that of the free enzyme, while the catalytic activity reached about 30% of that of a free enzyme. The study was reported in a recent issue of *Angewandte Chemie*.

NEW IX RESIN

Lanxess AG (Cologne, Germany; www.lewatit.com has added Lewatit TP 308 to its range of selective ion-exchange (IX) resins, which are suitable for the purification of lithium salt solutions. The macroporous Lewatit TP 308 has been developed specifically to treat low-concentration lithium salt solutions (<2 g/L) con-

(Continues on p. 6)

Recycling polyesters, polycarbonates and more — at room temperature

A new catalytic recycling method that avoids harsh processing conditions could widely expand the recyclability of a broad range of plastics, including polycarbonates, polyesters and mixed-waste feeds. Researchers from the Center for Sustainable and Circular Technologies (CSCT; www.ccst.ac.uk) at the University of Bath (www.bath.ac.uk) reported that the process, which employs a zinc-based catalyst and methanol, could fully break down poly-bisphenol A carbonate (BPA-PC) beads into bisphenol A (BPA) and dimethyl carbonate (DMC) in just 20 min at room temperature. By efficiently breaking down BPA-PC, the catalyst not only handles a difficult-to-recycle waste stream, but it also prevents BPA, a harmful pollutant, from leaching into the environment.

This is said to be the first instance of metal-mediated BPC-PC methanolysis showing high activity at room temperature. In addition to methanolysis, the team investigated several chemical strategies, such as alcoholysis, glycolysis and aminolysis, to maximize the range of attainable products from different waste streams using the new catalyst. The catalyst can also break down other plastic materials, including polylactic acid (PLA), polyester amides (PEAs) and polyethylene terephthalate (PET). Traditional recycling technologies for these materials include energy-intensive processes like pyrolysis or hydrosilylation, so the ability to rapidly recycle them into their chemical constituents at ambient conditions brings many economic and sustainability benefits. The team has demonstrated the technology at laboratory scale, and work is ongoing to scale up the reaction volume.

taining alkali, alkaline earth and heavy metals at relatively high concentrations, ranging from 100 mg up to several grams per liter. Such solutions occur, for example, during the treatment of geothermal brine following the desorption from primary adsorber material. The removal of the polyvalent ions — mainly calcium — from these solutions takes place very efficiently, with low leakage, and at high flowrates owing to the exceptional exchange kinetics. At the same time, the pressure drop across the resin bed is low.

The resin has a high total capacity of more than 4.3 equivalents per liter, which translates into longer intervals between the regeneration phases than standard resins. This reduces the amount of regeneration chemicals and water required, the company says.

MOLECULAR SIEVE

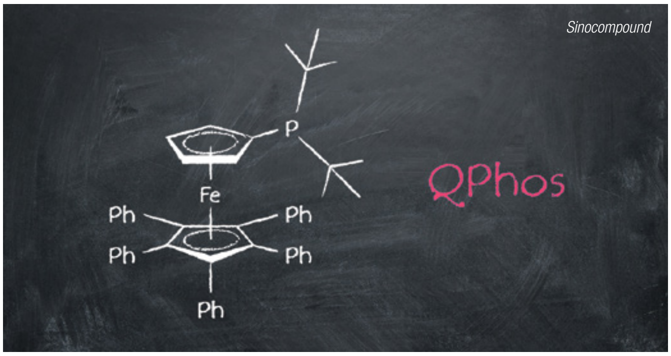
Graphene has many remarkable properties, but because the material has no pores, it cannot act alone as a molecular sieve without piercing the material with high precision pores. There have been many attempts to do this, but the result has been unfruitful due to a breakdown in structural integrity. Although it has been known since 2010 that 2-D silicon dioxide has pores naturally in its crystal lattice, it is very expensive to manufacture, and can only be done on a small scale. Now, scientists at Bielefeld University (www.uni-bielefeld.de), Ruhr-University Bochum (both Germany; www.ruhr-uni.de) and Yale University (New Haven, Conn.; www.yale.edu) have developed a fabrication process for making a layer of porous, 2-D SiO_2. "This is very exciting because 2-D SiO_2 has a very high density of tiny pores by nature that is simply not possible to be created in artificial membranes," says Petr Dementyev from the Physics of Supramolecular Systems and Surfaces research group in Bielefeld.

As described in a recent issue of *Nano Letters*, the researchers devised a new material fabrication process, which used atomic-layer deposition to deposit a large-area single layer of SiO_2 on a gold/mica substrate. The film was then transferred onto Si_3N_4 windows for characterization. Permeation experiments with gaseous and vaporous sub-

(Continues on p. 8)

Phosphine-based ligand now available on the kilogram scale

Sinocompound Catalysts Co., Ltd. (Zhangjiagang, China; en.sinocompound.com) says it is now producing the phosphine-based QPhos ligand in kilogram quantities for commercial use. With this ligand now accessible on a large scale, scientists across the globe can incorporate QPhos-based catalysts into their drug discovery, screening and process-development programs to optimize and streamline product development.



QPhos is a promising ligand in metal-catalyzed cross-coupling reactions, which are fundamental to building carbon-carbon bonds featured in most drug scaffolds. However, until now QPhos has not been readily available in commercial quantities, hindering its adoption in process development and scale-up programs, says the company.

QPhos is a robust dialkylarylphosphine ligand (diagram) first developed by John Hartwig, the Henry Rapoport Professor of Chemistry at the University of California, Berkeley (hartwig.cchem.berkeley.edu) for metal-catalyzed cross-coupling reactions, and reported in a 2002 article published in *J. Org. Chem.* Bulky and electron-rich, QPhos performs "excellently" in many transformations, including α-arylation of carbonyl compounds and late-stage C–C bond formation, says the company.

"There's an enormous amount of untapped potential in ligands that scientists simply can't access on a large scale, so they discount them from their screening programs," says Carin Seechurn, associate director — Technology Solutions, Sinocompound. "Our capability to scale-up the QPhos ligand represents a significant milestone in improving ligand accessibility for researchers. As we continue to expand our manufacturing processes thanks to our new plant in Tongling, we're excited to provide more overlooked ligands and products commercially."

A simpler way to recover purified graphite from spent batteries

A new recycling process claims to significantly reduce the complexity of recovering graphite from spent lithium-ion battery (LIB) materials by leaching out impurities rather than leaching out metal. By extracting impurities and recovering high-grade graphite, the Hydro-to-Anode technology, developed by Ascend Elements, Inc. (Westborough, Mass.; www.ascendelements.com) and Koura Global (Waltham, Mass; www.kouraglobal.com), keeps all critical metals, such as Li, Co, Ni and Mn, in solution, which greatly simplifies the process flow for the production of LIB precursor materials.

"Typical LIB-recycling processes either destroy the graphite or recover lower-quality graphite that cannot be used in the manufacture of new batteries. Our process extracts and purifies graphite before the critical cathode materials are recovered," explains Eric Gratz, chief technology officer at Ascend Elements. The Hydro-to-Anode process has yielded over 99.9% pure graphite with comparable energy density and cycle life to "virgin" battery-grade graphite. In combination with Ascend's Hydro-to-Cathode technology, which separates impurities from Li, Ni, Mn and Co with significantly fewer steps than hydrometallurgy or pyrometallurgy processes, the Hydro-to-Anode process extends the company's capacity to recover more value from spent LIBs by producing both cathode and anode materials.

Currently, Ascend Elements is recovering and purifying graphite in small batches at its recycling and manufacturing facility in Westborough, Mass., and work is underway for a commercial-scale plant in Covington, Ga., says Gratz. The new plant is scheduled to start up in the third quarter of 2022, and it will process 30,000 metric tons per year (m.t./yr) of battery materials.

stances reveal the suspended material to be porous, but the membrane selectivity appears to diverge from the size exclusion principle. Whereas the passage of inert gas molecules is hindered, condensable species like water are found to cross vitreous bilayer silica a thousand times faster in accordance with their superficial affinity, the researchers report.

SMART CATALYST

In an effort to develop catalysts that allow better spatiotemporal control of chemical reactions, scientists from the Gwangju Institute of Science and Technology (South Korea; www.gist.ac.kr) have developed a "smart" catalyst that deactivates under ultraviolet (UV) illumination. "In contrast with previously reported photoresponsive catalysts for which light turns on the catalytic reaction, our catalysts exhibit the opposite behavior; that is, they deactivate when illuminated with UV light, offering a new mode of photoswitching," says professor Sukwon Hong.

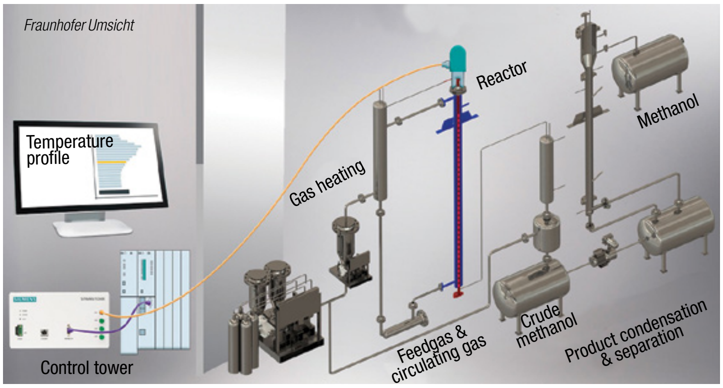
This feat was achieved by strategically combining a well-known ruthenium catalyst — cyclic(alkyl)(amino)carbene-ruthenium (CAAC-Ru) — with azobenzene, a photo-responsive organic compound. Their findings, described in a recent issue of *ACS Catalysis*, pave the way to new modes of photolithography and cooperative catalyst systems, the latter of which could be used for synthesizing sophisticated chemicals.

SEWAGE UTILIZATION

The Ministry for the Environment, Climate Protection and the Energy Sector of Baden-Württemberg, Germany is funding six new projects as part of the Bio-Economy Bio Up-Cycling program. One of the projects, named RoKKa, aims to demonstrate the viability of recovering raw materials from wastewater. "Until now, the task of a wastewater treatment plant was mainly to clean wastewater," says Marius Mohr, RoKKa project manager at the Fraunhofer Institute for Interfacial Engineering and

(Continues on p. 9)

Making 'green' methanol from steel-mill gases



A process that produces methanol from the gases generated at a steel mill will soon be field tested. The process has been under development for the last five years by researchers at the Fraunhofer Institute for Environmental, Safety and Energy Technology (Umsicht; Oberhausen, Germany; ww.umsicht.fraunhofer.de) as part of Carbon2Chem project (www.thyssenkrupp.com/en/carbon2chem). A demonstration-scale plant, which produces 2 L/h of methanol, has been successfully operating in Oberhausen.

The demonstration plant features a fiber-optic temperature-measurement system (diagram) with 36 measuring points along the reactor axis. They allow a detailed evaluation of the catalyst activity. "To further optimize the processes, we combined simulation and experimental studies at demonstration scale," says Andreas Menne head of the Low Carbon Technologies department. "At the same time, we would like to further link the results from the process simulation and the operation of the plant," says Menne. For this purpose, a digital twin of the plant is currently being created. In the future, it should be possible to control the plant in such a way that it can respond in advance to fluctuating boundary conditions, such as hydrogen availability, gas volume flows and gas compositions. Necessary maintenance intervals, for example to change or regenerate the catalytic converter, could also be planned precisely.

After the completion of this test phase in February, the demonstration plant will be moved to the Carbon2Chem technical center at a steel mill in Duisburg, Germany later this year. There, the demonstration plant will be operated under real industrial conditions until the end of the project term in May 2024.

Pilot plant to produce 'greener' acrylonitrile at cost parity for carbon fiber

A pilot facility currently under construction in Charleston, W.Va. will produce renewable acrylonitrile (ACN) without requiring the traditional petroleum-based propylene as feedstock. Since ACN is the raw material used to make carbon fibers, the new route to ACN allows the production of bio-based carbon fiber. Acrylonitrile is also used as the raw material for acrylonitrile-butadiene-styrene (ABS) plastic, acrylic fiber, nitrile butadiene rubber and acrylamide.

According to developer Trillium Renewable Chemicals (Knoxville, Tenn.; www.trilliumchemicals.com), the process cuts greenhouse gas emissions by 70% compared to the traditional propylene route, and uses a feedstock (glycerol) that is significantly cheaper than propylene. The Trillium process begins with glycerol, a byproduct of biodiesel manufacturing that is converted to acrolein via a dehydration reaction. Next, the acrolein undergoes an ammoxidation reaction in the presence of ammonia and oxygen to generate acrylonitrile.

The core innovation for the process is a proprietary catalyst for the dehydration that Trillium licensed from Southern Research Institute (Birmingham, Ala.; www.southernresearch.org). "The catalyst exhibits both high conversions in the reaction, as well as high selectivity," notes Trillium CEO Corey Tyree.

In 2014, Trillium began a partnership with Solvay SA (Brussels, Belgium; www.solvay.com), which was interested in a bio-based route to carbon fiber. Earlier this year, Trillium and Solvay announced a scientific partnership in which they intend to develop a supply chain for bio-based ACN. Now, Trillium is becoming qualified as a supplier of ACN for Solvay carbon fiber materials.

The pilot plant, which is slated for completion in mid-2022, will be followed by a larger demonstration plant in 2023 and a commercial-scale site in 2025, Tyree says.

Pilot plant for graphene production uses flash Joule heating

A pilot plant is scheduled to be completed later this year for the production of graphene using a technology known as flash Joule heating (FJH). Developed in the laboratory of James Tour at Rice University (Houston; www.rice.edu), FJH involves forcing brief pulses of high-voltage, high-current electrical current through a carbon-based material to quickly heat it to very high (~3,000K) temperatures.

"The high temperature breaks all the chemical bonds, allowing the non-carbon atoms to sublime out of the mix, while the carbon atoms form two-dimensional sheets of graphene," says Tour. "Because the pulse is so brief and the temperature rise so rapid, FJH has a much smaller carbon footprint than that of existing graphene-production methods," Tour adds.

The pilot plant is being constructed by a company Tour co-founded to commercialize the technology, called Universal Matter (Houston; www.universalmatter.com), which officially licensed the technology from Rice.

FJH overcomes a number of limitations observed in existing processes for making graphene, such as exfoliation of graphene layers from graphite. FJH can be carried out at substantially lower cost than other graphene-production methods, it generates a higher-purity graphene, and does not have the same environmental issues. In addition, the raw materials for FJH are low-cost and plentiful sources of carbon, such as petroleum coke, anthracitic coal, used tires and waste plastics. Graphene produced by FJH is in the form of a powder, which can be dispersed into a variety of materials to enhance strength, toughness, conductivity and other properties.

Another key differentiator for FJH is its ability to produce a form of graphene called turbostratic graphene. Graphene in this form has layers that are rotated slightly relative to each other, which minimizes inter-layer coupling and stacking (compared to conventional graphene) and makes it better able to disperse easily and evenly into other materials, Tour explains.

Beyond graphene production, FJH is a technique that can be applied to a widening range of materials-recycling applications, including harvesting precious metals from electronic waste and improving the extraction of rare-earth metals from waste streams like coal flyash.

Biotechnology (IGB; Stuttgart, Germany; www.igb.fraunhofer.de). "Now we are also looking at the raw materials contained in the wastewater." Scientists from Fraunhofer IGB, the University of Stuttgart, the University of Kassel and the Technical University of Kaiserslautern are working on the sustainable biorefinery, together with the companies SolarSpring, Deukum, Nanoscience for life, Umwelttechnik BW, the city of Erbach and the Steinhäule Treatment Plant Administrative Union.

For the recovery of phosphorous, IGB's ePhos process uses a sacrificial anode made of magnesium, enabling the phosphorus to be electrochemically precipitated as

(Continues on p. 10)

struvite. Two pilot plants separate the ammonium nitrogen from the sludge water: one plant uses membrane gas absorption with membrane contactors; the other uses of membrane distillation. Other efforts in the project are to reduce nitrous oxide emissions, and to electrochemically convert some of the CO_2 emissions, which are generated from the biogas digester, into formate, a raw material for the chemical industry. Microalgae that metabolize CO_2 and nutrients are also used to produce plant fortifiers and agricultural soil conditioners.

Selective separation of individual rare-earth elements using DGA-based ligands

Utilizing rare-earth elements (REEs), such as for permanent magnets in renewable energy applications, requires costly chemical separations that generate large volumes of waste. A process featuring new diglycolamide (DGA)-based ligands and liquid-liquid extraction exhibits more effective separation of individual REEs, and will allow lower-cost processing of REE-containing ores.

The process was developed by Oak Ridge National Laboratory (ORNL; Oak Ridge, Tenn.; www.ornl.gov) and Idaho National Laboratory (Idaho Falls; www.inl.gov) through the U.S. Department of Energy's Critical Materials Institute (CMI), an Energy Innovation Hub. The technology was recently licensed by Marshallton Research Laboratories Inc. (Tobaccoville, N.C.; www.marshalltonlabs.com).

Traditional REE separation uses liquid-liquid extraction, in which a non-polar solvent containing specific ligand molecules is mixed with an aqueous REE solution. Ligand-REE complexes are extracted from the aqueous phase to the solvent. Purified REE ions are then recovered from the solvent, which is reused.

"REEs can be separated according to their ionic radius, but since the selectivity obtained is not very high with existing ligands, often based on organophosphorus extractants, a large number of extraction stages are required to obtain desirable purities of REEs, like neodymium and praseodymium, that are used in permanent magnets," explains Bruce Moyer, an ORNL corporate fellow and member of the CMI. "The new DGA-based ligands we have developed have alkyl groups that can be tailored to create different steric and electronic environments around the complexed ions."

Moyer points out that the new ligands have the ability to Increase the REE selectivity compared to traditional ligands, so separation can occur with far fewer extraction stages. This reduces both capital and operating costs.

Key to the improved selectivity of the DGA ligands for different REEs is their ability to form more rigid structures. "The rigidity of the DGA ligand structures makes it more difficult for the molecules to twist and adjust to accommodate elements with varying ionic radii as the ligands form coordination complexes," Moyer says. "Because of this, the ligand-ion binding strength has more variability across the series of REEs, making possible much greater selectivity among ions."

Marshallton and CMI are looking to scale up the process and optimize the extraction.

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Plant Watch

Repsol begins construction of Cartagena biofuels plant

March 8, 2022 — Repsol S.A. (Madrid, Spain; www.repsol.com) began construction work on the first advanced biofuels plant in Spain at the company's Cartagena refinery, which will produce fuels using waste from agriculture, food processing and other sources. The project includes infrastructure for the storage of around 300,000 metric tons (m.t.) of waste material.

Air Products and Sargas to build air separation unit in Oman

March 8, 2022 — Air Products (Lehigh Valley, Pa.; www.airproducts.com), together with Saudi Arabian Refrigerant Gases Company (Sargas), will build a new air separation unit at the Jindal Shadeed Iron & Steel facility in Sohar, Oman. The new unit will supply a total of over 400 m.t./d of oxygen and nitrogen to the facility.

Evonik expands supply of plant-derived cholesterol

March 4, 2022 — Evonik Industries AG (Essen, Germany; www.evonik.com) has boosted its production of plant-derived cholesterol at its site in Hanau, Germany. Plant-based cholesterol is a critical component for the manufacture of vaccines and gene therapies.

Adnoc and Proman to develop world-scale methanol production plant

March 4, 2022 — Abu Dhabi National Oil Co. (Adnoc; www.adnoc.ae) and Proman AG (Wollerau, Switzerland; www.proman.com) plan to develop the United Arab Emirates' first world-scale methanol production facility in Ruwais, Abu Dhabi. The new facility will have a production capacity of up to 1.8 million m.t./yr of methanol derived from natural gas.

Lenzing starts production at the world's largest lyocell fibers plant

March 3, 2022 — The Lenzing Group (Lenzing, Austria; www.lenzing.com) started production at its expansion project for lyocell wood-based fibers in Thailand. The new plant, the largest of its kind with a nameplate capacity of 100,000 m.t./yr, represents an investment of around €400 million.

Covestro starts up two new polycarbonate compounding lines in India

March 3, 2022 — Covestro AG (Leverkusen, Germany; www.covestro.com) started up two polycarbonate-compounding production lines at its Greater Noida plant near New Delhi, India. The new plants are intended to meet growing demand for compounded plastics in the automotive and electrical industries.

Orion Engineered Carbons opened a new carbon-black production line in Italy

March 2, 2022 — Orion Engineered Carbons S.A. (Luxembourg; www.orioncarbons.com) began commercial production from a new reactor for carbon black at Ravenna in Northern Italy. The new production line, which has a production capacity of 25,000 m.t./yr, produces both specialty and technical rubber carbon blacks, primarily for the European market.

BASF building new alkylethanolamines plant in Antwerp

March 2, 2022 — BASF SE (Ludwigshafen, Germany; www.basf.com) is building a world-scale production plant for alkylethanolamines at its *Verbund* site in Antwerp, Belgium. After the planned startup in 2024, the company will increase the global production capacity of its alkylethanolamines portfolio, including dimethylethanolamines (DMEOA) and methyldiethanolamines (MDEOA), by nearly 30% to more than 140,000 m.t./yr.

OQ Chemicals completes capacity expansion for tricyclodecane dimethanol

February 25, 2022 — OQ Chemicals GmbH (Monheim am Rhein, Germany; www.chemicals.oq.com) completed a capacity expansion for tricyclodecane dimethanol (TCD Alcohol DM) at its Oberhausen, Germany, site. TCD Alcohol DM is used in exterior coatings, adhesives, optical materials and more.

Borouge starts up fifth polypropylene unit at Ruwais complex

February 24, 2022 — Borouge, a joint venture (JV) between ADNOC and Borealis AG (Vienna, Austria; www.borealisgroup.com), started up its fifth polypropylene (PP) unit in Ruwais, Abu Dhabi. The new PP unit will be able to produce 480,000 m.t./yr, increasing Borouge's PP production capacity by more than 25%.

Mergers & Acquisitions

Hexpol acquires 70% stake in German polymer-compounding firm

March 9, 2022 — Hexpol AB (Malmö, Sweden; www.hexpol.com) has signed an agreement to acquire 70% of the shares in Almaak International GmbH, a specialist in recycled engineered polymer compounds based in Krefeld, Germany. The acquisition price amounts to approximately €70 million.

Sika acquires Canadian manufacturer of cementitious products and mortars

March 3, 2022 — Sika AG (Baar, Switzerland; www.sika.com) has acquired Sable Marco Inc., a manufacturer of cementitious products, mortars and polymeric sands headquartered in Pont Rouge, Canada. The acquisition will

open up new opportunities for Sika in the eastern region of Canada. The acquired business generates annual sales of CHF 20 million (around $21.6 million). Sable Marco operates one manufacturing plant near Québec City.

Sasol to sell European wax business to AWAX

March 3, 2022 — Sasol Ltd. (Johannesburg, South Africa; www.sasol.com) plans to sell its German subsidiary Sasol Wax GmbH to Italy-based AWAX S.p.a. Sasol Wax has two production facilities in Hamburg, Germany, one in the U.K. and one in Austria. Following the acquisition, it will operate under the name Hywax GmbH.

Neste and Marathon establish JV for production of renewable fuels

March 3, 2022 — Neste Corp. (Espoo, Finland; www.neste.com) is establishing a 50/50 JV with Marathon Petroleum Corp. (Findlay, Ohio; www.marathon.com). The JV will produce renewable diesel following a conversion project at Marathon's petroleum refinery in Martinez, Calif. The project will increase Neste's renewable products capacity by over 1 million m.t./yr. Production of renewable diesel is expected to start in late 2022, with the full capacity of 2.1 million m.t./yr online by late 2023.

Chevron to acquire Renewable Energy Group for $3.15 billion

February 28, 2022 — Chevron Corp. (San Ramon, Calif.; www.chevron.com) will acquire the outstanding shares of Renewable Energy Group, Inc. (REG; Ames, Iowa; www.regi.com) in an all-cash transaction valued at $3.15 billion. After closing of the acquisition, Chevron's renewable fuels business will be headquartered in Ames, Iowa.

Teijin and Fuji Design form alliance to advance carbon-fiber recycling

February 24, 2022 — Teijin Ltd. (Toyko; www.teijin.com) and Fuji Design Co. plan to collaborate on the production and commercialization of carbon-fiber reinforced plastic (CFRP) products made from recycled carbon fibers using Fuji Design's proprietary pyrolysis technology. The technology produces carbon fibers from used CFRP by removing matrix resins, while reportedly producing 90% less emissions than carbon fibers produced with virgin raw materials.

Arkema acquires adhesives manufacturer in China

February 22, 2022 — Arkema S.A. (Colombes, France; www.arkema.com) announced the acquisition of Shanghai Zhiguan Polymer Materials (PMP), a company specialized in hot-melt adhesives. With over €1 million in annual sales, PMP manufactures adhesives mainly used in the bonding of phones, tablets, laptops and more.

Celanese acquires Mobility & Materials assets from DuPont

February 18, 2022 — Celanese Corp. (Dallas, Tex.; www.celanese.com) will acquire a majority of the Mobility & Materials business of DuPont (Wilmington, Del.; www.dupont.com) for $11 billion. With the acquisition, Celanese acquires a broad portfolio of engineered thermoplastics and elastomers and a global production network of 29 facilities. ■

Mary Page Bailey

A Taste of Foods to Come

Biotechnology plays a key role in sustainably feeding a growing global population

IN BRIEF

- NEW PROTEIN SOURCES
- CULTURED MEATS
- FIRST PILOT PLANTS OPERATING
- MEDIA COSTS
- SCALEUP CHALLENGES

How are we going to feed 10 billion people using 35% less land by 2050? This was the question posed by Ian Roberts, chief technology officer at Bühler AG (Uzwil, Switzerland; www.buhlergroup.com) at a (virtual) press event last December. Reducing agricultural land usage is necessary to restore forests and wetlands, not only to sequester CO_2, but also to ensure the biodiversity in our ecosystem that is critical to life, explained Roberts. "This is where we believe new protein sources come into play, and we have to focus on them deeply," he said.

Bühler is not alone in this focus. In fact, the number of new startup companies developing new and alternative protein sources is growing explosively, not to mention the growing participation — and investment — by traditional food, pharmaceutical and chemical companies.

New protein sources

There are several fronts attempting to meet these challenges: traditional plant-based proteins (vegetarian and vegan meat-like products); cultured meat (growing real beef, pork, chicken, seafood and more from cells); and alternative protein sources (derived from insects or produced by genetically modified organisms and plants). There is also significant development work in controlled-environment agriculture and aquaculture (fish farming). What unifies each of these areas is feeding the population more sustainably, says David Ziskind, director of Engineering at Black & Veatch NextGen Ag (B&V; Overland Park, Kan.; www.bv.com).

"Sustainability has always been a focus at Black & Veatch, which has over 100 years of experience in infrastructure projects in wastewater treatment, oil and gas and more," Ziskind says. About five years ago, the company established the NextGen Ag group to apply its know-how of process and technology scaleup to these emerging food technologies. "The intersection of our activities with these new projects is perfect," he says. "After all, when you talk about scaleup for these new food products, there is an infrastructure component to it. You need a certain level of infrastructure to support it, from a water, wastewater, electricity standpoint. And there is definitely a sustainability angle to it. With traditional food and beverages, sustainability has been something like a bolt-on added at the top. In this new space, we see new companies — many with dedicated sustainability officers — essentially reinventing our food supply, and sustainability is being thought of from the bottom up," says Ziskind.

FIGURE 1. Cultured meats are produced in bioreactors (cultivators), such as the one shown here

Cultured meats

Although there is a tremendous amount of research and development (R&D) going on in new protein sources, this article focuses on cultivated meat, a topic that has captured the attention of the general public, as well as investors. According to the latest data, released last month by the Good Food Institute (GFI; Washington, D.C.; www.gfi.org), a record $5 billion was invested in alternative proteins in 2021, a 60% increase over 2020. Cultivated meat and seafood companies secured $1.4 billion in investments in 2021 — three times more than the $400 million raised in 2020. There are now more than 70 startup companies focused exclusively on developing cultivated meat inputs or end products, according to GFA's "2020 State of the Indus-

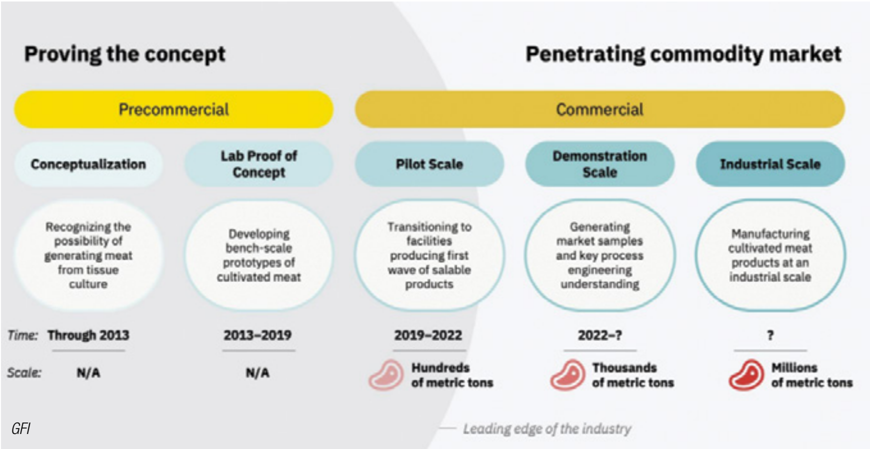


FIGURE 2. This diagram shows the projected timeline for cultured food products

try Report: Cultivated Meat," which was published last year (the 2021 report is expected to be published this month).

Some of the new cultured-meat companies were formed and are headed by biotechnologists and former cardiologists, because the technology used has roots in stem-cell research and treating heart patients.

Cultured meat is real meat that is grown from animal cells. Unlike the meat, fish, chicken and pork found in grocery shops, no animals need to be slaughtered to produce cultured meat. Instead, cells taken from living animals are grown in bioreactors or cultivators (Figure 1) at high densities and volumes. The cells are fed an oxygen-rich cell culture medium made up of nutrients, such as amino acids, glucose, vitamins, and inorganic salts, and supplemented with proteins and other growth factors, according to GFI's website.

Changes in the medium composition, often in tandem with cues from a scaffolding structure, trigger immature cells to differentiate into the skeletal muscle, fat and connective tissues that make up meat. The differentiated cells are then harvested, prepared and packaged into final products. This process is expected to take between two and eight weeks, depending on what kind of meat is being cultivated, according to GFI.

Although cultured meat and seafood has not yet been approved for human consumption by regulators around the world — with the exception of Singapore — there have been countless tasting events in California, Israel and elsewhere, and some restaurants offer dishes on their menu for customers willing to sign waivers regarding unknown health issues associated with such products.

While there are many uncertainties related to government approvals, labeling of future products that contain cultured meat, and scale up of production, there are many arguments in favor of this new source of meat. Cultured meat is sometimes referred to as "clean meat," because it is produced under sterile conditions and is free of hormones and other chemicals that can be found in some products from traditional livestock farming or seafood from polluted lakes or oceans, not to mention the risk of pandemics, antibody resistance and food insecurity. From a moral perspective, no animals need to be sacrificed. Perhaps the best argument in favor of cultured meat is the sustainability aspect referred to earlier.

The first lifecycle analysis that uses primary data from multiple cultured-meat companies and associated companies along the supply chain was published in February 2021 by CE Delft (the Netherlands; www.cedelft.eu). The study found that significant reductions in CO_2 equivalent (CO_2eq) emissions (by up to 92%), land usage (by up to 95%) and water usage (by 78%) can be achieved for all types of cultured meats — some more than others — when compared to conventional farming methods. So even though the environmental benefits of plant-based meats are greatest (99% reduction in CO_2eq emissions for plant-based beef compared to conventional beef from beef cattle), "not everyone needs to become vegan" to contribute to a sustainable diet, says Bühler's Roberts.

First pilot plants operating

Although the cultured meat industry is still very young, the first mini and pilot-scale production plants are now starting up and operating, with further scaleup anticipated soon (Figure 2). The following is a brief overview of some of the activity within the past six to eight months.

Last June, Future Meat Technologies (Rehovot, Israel; www.future-meat.com) opened its first pilot plant (Figure 3), which has a capacity to produce cultured chicken, pork and lamb products, all produced without the use of animal serum or genetic modification. The company says its process enables fast production cycles that are about 20 times faster than traditional animal agriculture, while using 99% less land and 96% less water, as well as generating 80% less greenhouse-gas emissions. The company is also working on the production of beef, and plans to bring products into the market this year, as well as "scouting several locations in the U.S. for its projected large-scale production facility," the company says. In December 2021, Future Meat raised $347 million in Series B round financing, which was co-led by ADM Ventures, the investment arm of the Archer-Daniels-Midlands Co. (ADM; Chicago, Ill.; www.adm.com).

According to Future Meat, its proprietary technology is based on stainless-steel fermenters that continuously remove waste products generated by "immortal" tissue cells, thereby maintaining a constant physiological environment that supports rapid, natural, proliferation of animal cells. This connective-tissue method has been shown to be more robust and efficient than others using stem cells, and its rejuvenating fermenters can recycle over 70% of the nutrients, the company says.

Also last June, Wildtype Foods (San Francisco, Calif.; www.wildtypefoods.com) started operations at its first pilot plant in San Francisco, Calif. for the production of salmon products. The facility also features a sushi bar (tasting room) for visitors.

Meanwhile, Upside Foods (Berkeley, Calif.; www.upsidefoods.com) completed construction of its Engineering, Production and Innovation Center (EPIC) in Emeryville, Calif. last November. The 53,000-ft^2 campus is designed to produce any species of meat, poultry and seafood directly from animal cells. Patented, custom-made cultivators (Figures 1 and 4) can produce over 50,000 lb/yr of finished product, with a future capacity to over 400,000 lb/yr. Initially, the company started producing meat for its group of restaurant partners. The company — formerly known as Memphis Meats — introduced the world's first cultivated meatball in February 2016 and the world's first cultivated poultry in March 2017.

Also in November, Shiok Meats (Singapore; www.shiokmeats.com) officially opened its first-of-a-kind R&D facility for cultivated seafood. B&V collaborated with Shiok Meats for the conceptual design and layout of this facility, which will help Shiok Meats, the world's first cultivated crustacean company, scale-up production of cell-based crustacean meat products, targeting commercialization by 2023.

"Building the Mini Plant is a big milestone for us," said Sandhya Sriram, group CEO & co-founder, Shiok Meats at the opening of the plant. "Our production facility, which is due in the next 18 months, will be an extension of this Mini Plant in terms of engineering design and foundation. This new facility allows us to scale the cultivated seafood production gradually and strategically to ensure a comprehensive manufacturing model and top-notch products," she said.

Meanwhile BlueNalu, Inc. (San Diego, Calif; www.bluenalu.com) is scaling up to pilot scale. "The completion of our pilot production facility and the preparation to achieve regulatory requirements needed by the U.S. FDA for our cell-cultured seafood products are both currently in process," says Lou Cooperhouse, the company's co-founder, president and CEO. "Our new BlueNalu Innovation Center will be 40,000 ft^2 and will incorporate a processing environment that enables production of limited volumes under Good Manufacturing Practices (GMP) conditions and global best practices in food safety. This will enable us to continually ideate, innovate and introduce new species, and new forms and packaging options for our customers and consumers," he says.

"We have developed a multi-species platform technology in which we are initially developing finfish products that include pacific bluefin tuna," explains Cooperhouse. "We are specifically targeting species that are overfished, primarily imported and difficult to farm-raise. It is our goal, as a result of this strategy, to reduce fishery pressure, complement the existing seafood supply chain, displace the need for imports, create jobs, enhance food security, and offer the ultimate seafood experience in each region we go to market," he says.

Meanwhile, The Cultured Food Innovation Hub will start up in Kempttal near Zurich this year. This new facility for developing cellular agricultural products was established by Swiss companies Givaudan (Vernier; www.givaudan.com), Bühler and Migros (Migros-Industrie Migros-Genossenschafts-Bund; Zurich; www.mgb.ch). The Cultured Food Innovation Hub aims to accelerate the development and market penetration of cellular agriculture products.

The new entity provides facilities and knowledge to accelerate other companies on their cultured meat, cultured fish and seafood, and precision-fermentation developments. The Hub will be equipped with a product-development laboratory, as well as cell culture and bio-fermentation capabilities to help start-ups develop and go to market with the right product.

Media costs

Growth media is estimated to account for 50–90% of production costs of cultured meat, so efforts are underway to reduce these costs, which will ultimately make cultivated meat products more affordable. Last October, for example, Mosa Meat (Maastricht; www.mosameat.com) and Nutreco N.V. (Amersfoort, both the Netherlands; www.nutreco.com) were awarded nearly €2-million funding from the European REACT-EU recovery assistance program to advance cellular agriculture and bring cultivated beef to the E.U. market. The funding for this "Feed for Meat" project is being used to address the "basal" or base media in which beef cells grow. By moving away from pharmaceutical-grade products and instead using feed- and food-grade byproducts from Nutreco's supply chain, Mosa Meat believes it can substantially lower costs of basal media. Mosa Meat introduced the world's first cultivated beef burger in 2013, and has since received backing from Blue Horizon, Bell Foods Group, Nutreco, Mitsubishi Corp., Leonardo DiCaprio, and others.

In a related project, Meatable (Delft; www.meatable.com) entered a joint-development agreement last September with Royal DSM N.V. (Heerlen, both the Netherlands; www.dsm.com) to develop growth media for cultivated meat.

Last December, Wacker Chemie AG (Munich, Germany; www.wacker.com) entered a partnership with Aleph Farms (Rehovot, Israel; www.aleph-farms.com) to develop streamlined production processes for growth medium proteins, which "we believe are key to bringing down the overall cost of cultivated products," says Oliver Minge, head of

FIGURE 3. An inside view of the the first industrial cultured meat facility in Rehovot, Israel

FIGURE 4. A view from the control room of Upside Foods' Engineering, Production and Innovation Center in Emeryville, Calif.

Innovation Biosolutions at Wacker. "We also believe that as the industry grows, we will need to build up a supply chain for these compounds that satisfies the food industry's requirements and regulations."

Scaleup challenges

Supply chain issues may also hinder progress as companies complete their pilot phase and look to build commercial plants. Scaleup will require good planning in advance, says B&V's Ziskind. One of the challenges will be the capacity to manufacture more bioreactors. "There is a certain lead time for a large-scale piece of equipment, and it might take a year or even longer before you get it," explains Ziskind. "Think of all the innovation and the movement in this space. You could order a piece of equipment today to be delivered in 2023, but the way things change, it might not be the right size or isn't the right technology by the time it arrives. Companies need to be forward-focused," he says.

Nevertheless, "every basic technology needed for cultivated meat production has been developed and there is no missing part or aspect that would need to be invented first [before scaling up to industrial scale]," says Wacker Chemie's Minge. The main technical challenge he sees today is the following: "Unlike microbial cells, mammalian cells take longer to grow and are generally more prone to impurities. They therefore need a higher level of cleanness when being grown. Maintaining a clean environment, however, becomes more difficult and more expensive, the larger your overall production volumes are," he says. Minge believes the largest vessels for mammalian cell cultures in the pharma business today are in the range of 20,000 L. "Some people argue that volumes above 100,000 L would be hard to achieve. I am more optimistic here: on the one hand, it has been shown that for another very delicate type of cell (plant cells), production on a 100,000-L scale is feasible; on the other hand, I think that there are also alternatives to scaling up a batch process, for example scaling out or continuous production." ■

Gerald Ondrey

More Sustainable Cleaning Solutions Increase Efficiency

Processors no longer need to sacrifice efficiency or effectiveness when selecting eco-friendly housekeeping methods

Commitment to environmental, social and corporate-governance programs coupled with a pandemic-induced need for more effective sanitizing are forcing chemical, pharmaceutical, food-and-beverage and other processors to reevaluate their industrial housekeeping products, practices and programs. Fortunately, today's more-sustainable methodologies not only effectively tackle common housekeeping issues, but also reduce cleaning-related downtime.

It's no surprise that every processor has different needs and challenges when it comes to tidying the facility; the chemical sector has a different set of housekeeping challenges than the food-and-beverage industry, whose needs differ from the pharmaceutical industry, whose problem areas vary from those in the oil-and-gas or plastic industries. "Each industry has different regulations in place regarding cleaning practices, with some more stringent than others. Each industry has different equipment that comes with its own cleaning requirements and challenges," notes Steve Wilson, applications development director, with Cold Jet (Loveland, Ohio; www.coldjet.com). "And, each industry has different contaminants or soils and different substrates."

"This means every processor has to figure out the right recipe and method for removing their particular soils from their particular substrate in a way that meets applicable guidelines and regulations," he continues.

In the past, this was often accomplished via solvents or water (or both), but processors are moving away from these housekeeping methods. "Almost all processors are beginning to look at their environmental and social impact and trying to find ways to reduce greenhouse gas (GHG) emissions. They are finding that many of the solvents used for housekeeping are sources of HFCs [hydrofluorocarbons], CFCs [chlorofluorocarbons] and other man-made gases and want to avoid that," Wilson says. "They also want to reduce water use in their plants due to issues surrounding water scarcity, as well as the cost of raw water and water treatment. And, since traditional industrial cleaning and sanitizing methods use a lot of water (about 40% of water use in industrial facilities is attributed to cleaning), processors are trying to reduce or eliminate aqueous-intensive cleaning in their facilities."

FIGURE 1. TOMI's SteraMist disinfection products use ionized hydrogen peroxide (iHP) technology. Available surface units, fogging systems and cordless backpack units provide disinfection and decontamination via an active ingredient of 7.8% H_2O_2

In addition to the environmental impetus, the pandemic heightened the need for better sanitation methods. "Not only can traditional, manual cleaning methods be time-consuming and introduce cross contamination, but during the pandemic, we learned that manual methods were not doing a good job killing viruses, bacteria and other contaminants," says Halden Shane, CEO and chairman of the board with TOMI Environmental Solutions (Frederick, Md.; www.tomimist.com). "For this reason, they are looking for methods that are not only greener, but are also more mechanical, which also ticks the box of being more efficient."

Moving to mechanical methods

"Processors want to spend as little time as possible cleaning and disinfecting, so they are looking for ways to clean both process equipment and general-use areas in a way that maximizes efficiency while still providing a high level of sanitation," explains Shane. "For this reason, there is a shift from manual to mechanical methods that increase both efficiency and environmental and social ethicacy."

For example, TOMI's SteraMist disinfection products use ionized hydrogen peroxide (iHP) technology. Each product, including a surface unit, an environmental fogging system and a cordless backpack unit, provides versatile disinfection and decontamination via an active ingredient of 7.8% H_2O_2 (Figure 1).

The patented Binary Ionization Technology activates and ionizes a 7.8% H_2O_2 sole active-ingredient-based solution into a fine mist/fog known as iHP. Ionized hydrogen peroxide contains a high concentration of reactive oxygen species (ROS), consisting mostly of hydroxyl

FIGURE 2. Dry ice cleaning uses solid carbon dioxide pellets or microparticles, which are blasted at supersonic speeds and sublimate on impact, lifting dirt and contaminants off the underlying substrate. The process is non-abrasive, non-conductive, non-flammable and non-toxic

radicals. Using TOMI's process and products, these hydroxyl radicals can kill bacteria and fungal spores and inactivate viral cells by destroying their proteins, carbohydrates and lipids. This leads to cellular disruption or dysfunction, allowing quick decontamination of targeted areas, objects and large spaces.

The technology offers no wipe, no-rinse, no residue, non-corrosive, high-level efficacy, quick turnaround time and superior material compatibility, allowing it to be sprayed directly on sensitive equipment, while the sub-micron particles allow the mist/fog to reach every area being treated.

The technology can be used to disinfect and sanitize chemical, life sciences, food-and-beverage and pharmaceutical process equipment, laboratories and cleanrooms, as well as general facility areas, according to Shane. Traditionally, electrostatic sprayers would have been used in these applications, but they typically spray large micron-sized droplets, which develop a wetness that damages surfaces. "Using our technology to achieve very small sub-micron sizes, we can get down to the level of bacteria and virus to kill them, versus drowning them with over-wetness that damages materials and equipment," Shane says.

"Not only is it less damaging, but it's faster and uses less manpower," he continues. "Users press a button and fill a room to cover all surfaces with minimal work and minimal downtime because there is no rinsing and it leaves no residue. On top of that, we leave behind no toxic by-products, so it's ecofriendly."

Dry-ice cleaning is also finding applications in chemical processing facilities, including those in the life sciences, food-and-beverage, cannabis, plastics, oil-and-gas and any industry that requires a dry, non-abrasive cleaning method, says Cold Jet's Wilson.

Also known as dry-ice blasting, dry-ice cleaning is an environmentally responsible cleaning and surface preparation technique, similar to sand, bead and soda blasting in that it prepares and cleans surfaces using a media accelerated in a pressurized air stream. However, it differs in that dry ice cleaning uses solid carbon dioxide pellets or microparticles, which are blasted at supersonic speeds and sublimate on impact, lifting dirt and contaminants off the underlying substrate. The process is non-abrasive, non-conductive, non-flammable and non-toxic. The dry-ice blasting process also does not create secondary waste as the dry ice sublimates, or phase transitions, from solid CO_2 to gaseous CO_2 when it impacts the surface being cleaned (Figure 2).

"As companies are getting more serious about environmental and social governance, they are looking at their contributions to greenhouse gas emissions," says Wilson. "Since CO_2 is naturally found in the environment and dry ice is made from recycled CO_2, it doesn't count toward a processor's greenhouse gas emissions, as it has already been accounted for at the source of the original emission. Because it's a reclaimed substance, it's a way to help reduce their carbon footprint score, as it can be used in place of solvents."

Another eco-friendly aspect of dry-ice cleaning is that it's a dry method of cleaning, helping to eliminate the use of water. "With other methods, there is sometimes a residue left behind, which needs to be removed. With dry ice, there is no residue as it sublimates," says Wilson.

This also contributes to efficiency. "We have case studies in industry where a dozen employees performed cleaning tasks using traditional aqueous methods, but after switching to dry ice, only one to three people were needed. Dry ice is faster because there is no masking to protect areas that cannot get wet, users don't have to wait for equipment or areas to cool down before cleaning and it is not necessary to calculate the nature of the soil and the concentration of solvent needed to remove it as dry ice blasting can clean any number of soils from any number of substrates," he says. "All this comes together to simplify and streamline the cleaning process."

Minimizing cleaning time and water

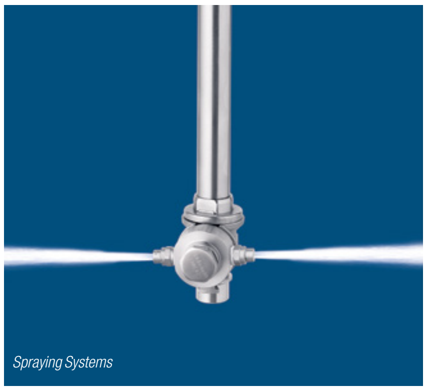


FIGURE 3. Spraying Systems' motor-driven tank cleaners, including the TankJet AA190, can help resolve time, effectiveness and water usage woes, as they can be slowed down or sped up via controls, optimizing the process

usage is also essential when it comes to cleaning batch reactor tanks and storage tanks, says Bandish Patel, director of the industrial division at Spraying Systems Co. (Glendale Heights, Ill.; www.spray.com). "Processors want to minimize downtime between batches in reactor and storage tanks because they need them back in service as soon as possible," he says. "Traditionally, the cleaning process was 'fill and drain,' where the tank was filled with cleaning chemicals, water or a mixture of both, which used a lot of water, and was left to sit. The tank then had to be completely drained and rinsed and, depending on the chemicals or solution, that water often had to be captured and disposed of safely."

Static spray balls with multiple jets and rinsing were another traditional method of cleaning tanks. "Processors were relying on time and the spray ball to spray multiple jets onto the walls, which was high in water usage and time because the chemicals had to be left on for a long period and required a lot of water to rinse," he says.

Modern tank cleaning systems, such as Spraying Systems' TankJet line (Figure 3), especially electrical-motor or compressed-air driven tank cleaners, can help resolve time, effectiveness and water usage woes as they can be slowed down or sped up via controls, which helps optimize the process, says Patel. "You want to be able to spray your caustic quickly. Modern controls for tank cleaning equipment allow you to speed the motor and rotation to get the chemical on as fast as possible, using as little chemical as possible. Then, when you enter the scrub cycle, the jets can be slowed down to provide higher impact cleaning action. Once it's done, controls allow users to quickly rinse the tank, reducing water usage by once again upping the ro-

PathoSans

FIGURE 4. **PathoSans technology produces environmentally responsible, electrochemically activated sustainable solutions in the processor's facility. Onsite generation equipment uses patented electrochemical activation to produce cleaning and sanitizing solutions using just salt, water and electricity in ready-to-use concentrations that can replace traditional toxic chemicals**

FIGURE 5. Processors can expect to see a lot of the current consumer trends transition into industrial applications, including bio-renewable surfactants and palm-free surfactants, as well as the potential for new and upcoming technologies around microbial cleaners

tation speed. This control allows you to speed the cleaning process, while also minimizing chemicals and water, helping processors become more sustainable and efficient, while also reducing the costs."

Greener, effective formulations

Obviously, a significant part of greener cleaning involves the cleaning formulations themselves; however, no one wants to trade effectiveness for sustainability. For this reason, cleaning product formulators are creating greener and more effective formulas. This is especially true in process industries, such as food and pharmaceuticals where very strict cleaning regulations from government agencies exist and where specialized and difficult-to-clean equipment, such as blenders, high-shear granulation and fluidized beds, have to be cleaned, sanitized and neutralized between batches, says Aaron Martin, regional account manager with PathoSans (Glendale Heights, Ill.; www.pathosans.com).

"Cleaning and disinfecting specialized process equipment can be challenging, so processors need a system that meets the regulatory requirements, their own safety operating procedures and can work in conjunction with clean-in-place (CIP) or clean-out-of-place (COP) systems," he says. "And while they want the products to be effective, they are also looking at sustainability."

PathoSans technology produces environmentally responsible, electrochemically activated sustainable solutions in the processor's facility, explains Martin (Figure 4). "Our onsite generation equipment uses patented electrochemical activation to produce safe cleaning and sanitizing solutions using just salt, water and electricity in ready-to-use concentrations that can replace traditional toxic chemicals," he says. "The produced cleaner and sanitizer are non-irritating to eyes and skin and are fragrance and residue free, making them suitable for use on sensitive process equipment, as well as general cleaning throughout the plant.

"And because they are electrochemically activated solutions, they are cleaning more aggressively with less impact on the environment both outside and inside the plant where they can be used to clean without adverse side effects like corrosion and oxidation," Martin continues.

As for the future of greener cleaning formulations, processors can expect to see a lot of the current consumer trends transition into industrial applications, says Aaron Lee, global vice president for home care and industrial cleaning, with Univar Solutions (Downers Grove, Ill; www.univarsolutions.com) (Figure 5). "Everyone is interested in natural and green solutions and this means bio-renewable and palm-free surfactants will continue to be a growing trend," he says. "There is also some new and upcoming technology around microbial cleaners, which may actually extend the cleaning life, making them potentially ideal for use in open-plant cleaning where users would lay down the product and have the cleaning last for 24 hours to several days, which decreases the amount of physical cleaning employees would need to do."

He says formulators are currently working on ways to take a microbial surfactant and enzymes and create a hard surface cleaner for industry.

"Creating a routine schedule of cleaning and housekeeping helps to set the expectations for the state of the production space and ensure a safe, efficient environment for processing," says Brad Sims, food division team leader with Madison Chemical Co., Inc. (Madison, Ind.; www.madchem.com). "Cleaning on an 'as needed' type of schedule can lead to oversight and failure to maintain the equipment and environment in good working condition." Instead, he says, a routine cleaning and maintenance schedule using today's more modern and efficient solutions will help ensure the productivity of the process, as well as the longevity of equipment and tools used in the processing of chemicals and other products (Figure 6).

Spraying Systems' Patel agrees: "Within all these facilities, the real objective is making product. No one wants extended downtime for cleaning. We are fortunate to have options for more efficient and ecofriendly solutions, providing better ways to clean and maintain a process facility and its equipment." ■

Joy LePree

FIGURE 6. A routine cleaning and maintenance schedule using modern and efficient solutions will help ensure productivity. Shown here is ProClean Foam Safe, which, when used in a "foam generator" as a one-package cleaner, produces thick, stable, wet foam for cleaning without dry out or run off

Focus on Analyzers

ColoidTek

Endress+Hauser

Signal Group

ECD Analyzers

Measure every liquids' 'fingerprint' in real time

This company has developed a new radio-wave-based analysis technology that enables continuous monitoring of the state of any liquid, including thick slurries, resins, adhesives, coatings, emulsions, beer, water and more. The Collo Analyzer (photo) has an electromagnetic resonator that emits a continuous radio-frequency field into the liquid. The signal reacts to interferences caused by different components, chemicals and phases in the liquid. The analyzer immediately warns if the process is disturbed in any way so that the process can be adjusted according to the online data. The sensors can be placed anywhere in the process to optimize, for instance, the use of raw materials and chemicals in critical process steps. In brewing, for example, the Collo Analyzer simultaneously measures eight proprietary parameters from a liquid, which together form the liquid's fingerprint. If these characteristics are changed during processing, the analyzer shows the changes so that corrective measures can be taken immediately. — *ColloidTek Oy, Tampere, Finland*
www.collo.fi

Color measurement moves from the lab to the process

Color measurements are employed for quality control and safety in many sectors of the chemical process industries (CPI), including life sciences, food, chemicals and petrochemicals. In many cases, the samples are taken from production and brought to the laboratory where they are analyzed, after which the batch is released. Shifting this step directly to the process enables real-time monitoring and control, particularly across the entire production process. The Memosens Wave CKI50 process spectrometer (photo) enables robust inline quality control. Using visible (VIS) absorption spectroscopy, the CKI50 scans the 380–830-nm wavelength range of the electromagnetic spectrum and outputs the color in the form of a 3-D color-space model, which enables the device to determine colors, color variations or the accuracy of the expected colors. The mathematical analysis models required to analyze the spectroscopic results are stored in the instrument. The CKI50 uses the Memosens protocol to connect to the Liquiline transmitter, which forwards the data to the process control system. — *Endress+Hauser AG, Reinach BL, Switzerland*
www.endress.com

This TDLS ammonia analyzer operates with a tablet

This company was asked to develop an ammonia analyzer that could be used in the research and development of ammonia-powered engines. The requirements for this application included features such as high selectivity for ammonia, fast response time, low maintenance/calibration requirements, long-term reliability and the ability to measure a hot/wet gas continuously. Tunable diode laser spectroscopy (TDLS) meets all of these requirements, so the company built the analyzer into its Series 4 range to make the S4 Nebula (photo). The analyzer features a detachable tablet, which enables users to operate the analyzer wirelessly from a convenient location nearby, using the instrument's built-in Wi-Fi. — *Signal Group Ltd., Camberley, Surrey, U.K.*
www.signal-group.com

Multifunction analyzer for boiler-water treatment

The CE800 Series (photo) is a family of online cation conductivity analyzers that detect a wide range of contaminants, which contribute to the buildup of corrosion and scale in boilers, turbines, piping and other expensive equipment that requires maintenance and shortens life. Cation conductivity is the measure of electrolytic conductivity of a liquid sample after that liquid sample has passed through an ion-exchange resin column. The conductivity of makeup water, feed water and condensate, after passing through this column of strongly acidic cation exchanger resin, is an important chemical mea-

surement used in steam generating power and other industrial plants depending on boilers for steam process heating. The CE800 also measures pH, which provides an additional parameter of importance to ensure water quality in the plant. The cation resin converts low-conductivity mineral ions, such as Na^+, Ca^{2+} and Mg^{2+}, to form an acid, which has a high conductivity level H^+ ion. This acid form has a conductivity that is three- to six-times greater than the corresponding salt, so the sensor is much more sensitive, effective and reliable in measuring water impurities than other methods. — *ECD Analyzers, a subsidiary of Electro-Chemical Devices, Inc., Anaheim, Calif.*
www.ecdi.com

New mass spectrometer for compound identification

The BenchTOF2 (photo) is a next-generation mass spectrometer for gas chromatography (GC) and two-dimensional GC (GC×GC). Through enhanced sensitivity, improved spectral quality, heightened selectivity and an extended dynamic range, the BenchTOF2 is said to maximize the amount of information extracted from every single sample, and removes the guesswork associated with compound identification. BenchTOF2 has detection limits of less than 20 femtograms (20×10^{-15} g), improved match factors and isotope abundancies, mass accuracy of less than 50 parts per million (ppm) and advanced software, which includes isotope overlays, tools for automated filtering of chromatograms and a mass-to-formula calculator. — *SepSolve Analytical Ltd., Peterborough, U.K.*
www.sepsolve.com

The first net-zero mass spectrometer introduced

The Delta Q isotope ratio mass spectrometer (IRMS; photo) is a next generation gas IRMS designed to enable detailed analysis with greater precision and accuracy. In addition to its improved specifications, including an upgrade in software to Qtegra ISDS to dramatically improve ease-of-use and laboratory productivity, the system's carbon footprint will be neutralized, allowing scientists to carry out their work, while minimizing their environmental impact. The Delta Q IRMS is the first product released as part of the Iso-Footprint campaign, an initiative to permanently remove CO_2 emissions associated with the manufacture and supply chain of all new inorganic IRMS products. — *Thermo Fisher Scientific Inc., Bremen, Germany*
www.thermofisher.com

This gas analyzer has new digital communication abilities

Purpose-built to detect ultra-low concentrations of NOx (oxides of nitrogen) emissions in industrial and commercial combustion applications, the new Rosemount XECLD process gas analyzer (photo) leverages the digital architecture of the Rosemount X-Stream Enhanced (XE) suite of continuous gas analyzers to offer a full range of web-based communication capabilities, including secure, remote connectivity without the installation of additional software. The XECLD utilizes chemiluminescence measurement technology with a thermoelectrically cooled, solid-state detector assembly to ensure highly stable measurement performance and a longer operating life. User-selectable NOx measurement ranges are from 0–5 up to 10,000 ppm. — *Emerson, St. Louis, Mo.*
www.emerson.com

Taking elemental analysis to the next level

The Spectro Arcos inductively coupled plasma, optical-emission spectrometer (ICP-OES; photo) precisely analyzes the elemental composition of metals, chemicals, petrochemicals, and more. The new enhancements introduced in the instrument include: a new dual side-on interface (DSOI) plasma viewing option featuring two optical interfaces; a MultiView plasma viewing option; advanced line-array detectors, based on complementary metal-oxide-semiconductor (CMOS) technology, which are said to be equal to or surpass the performance of legacy charged-coupled device (CCD) detectors; and more. The system delivers a high resolution over a wide spectral range (130–770 nm), as well as ultra-high-speed readout (simple matrices can be analyzed in 30 s). — *Spectro Analytical Instruments GmbH, Kleve, Germany*
www.spectro.com ■

Gerald Ondrey

SepSolve Analytical


Thermo Fisher Scientific

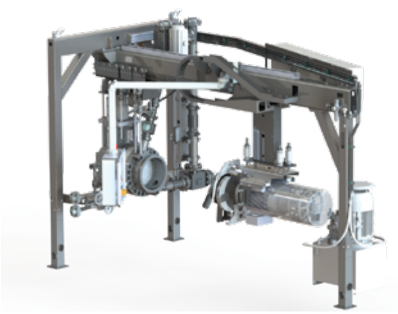
Emerson


Spectro Analytical Instruments

New Products

Blue-White Industries

Lödige Process Technology



Maag Pump Systems

WIKA Alexander Wiegand

R. Stahl

Multi-diaphragm dosing pump is virtually maintenance-free

The Chem-Feed CD1 (photo) is engineered to ensure almost no maintenance requirement for the life of the pump. CD1 is suitable for dosing with gas-forming chemicals, such as peracetic acid or sodium hypochlorite. The CD1 Dual Diaphragm Hyperlink Drive Technology pumps chemicals continuously, is self-priming and will not vapor lock. Engineered for zero maintenance, the CD1 includes the patented ultra-durable diaphragm, called DiaFlex, which is an exclusive single-layer diaphragm designed to last the life of the pump. The CD1 has a dosing rate of up to 7.70 gal/h (29.2 L/h) and is easy to install and operate. — *Blue-White Industries Ltd., Huntington Beach, Calif.*
www.blue-white.com

An efficient cleaning system for mixers

Automatic WIP-Systems (photo) provide a reliable and repeatable process for cleaning mixing systems — such as the Ploughshare Mixers — an important task especially in life-science applications. A smart arrangement of rotating cleaning nozzles inside the mixing drum ensures a thorough rinsing of all product contact surfaces without any need for filling the machine with cleaning media. By simultaneous rotation of mixing elements and cleaning nozzles, any spray shadows are avoided. The gear-driven rotating flat fan nozzles guarantee an intensive and uniform cleaning of all surfaces. Besides the rotating cleaning nozzles inside the mixing drum, the seals for the mixing elements and choppers are purged with water and all ports on the machine are cleaned effectively by static, locally installed cleaning nozzles. — *Lödige Process Technology, Paderborn, Germany*
www.loedige.de

A polymer pelletizer for when capacities are high

The Pearlo 350 EAC underwater pelletizing system (photo) has a liquid-heated die plate for high capacities, delivering throughputs of 18,000 kg/h of virgin polymer. The unique cutting-blade design and optimum water- and material-flow conditions within the cutting chamber provide not only ideal and homogeneous cooling effects, but also outstanding pellet quality, says the company. Another design feature is the cutting-blade advance system, which permits axial movement of the cutter shaft, resulting in a precise blade advance, as well as a regrinding of the blades during production. This allows higher equipment availability and lengthened production runs, which saves costs. — *Maag Pump Systems, Oberglatt, Switzerland*
www.maag.com

A compact pressure gage system for emission control

The new Emission Control Gauge (EMICOgauge; photo) pressure-measuring system features the assembly of a model 2xx.30 pressure gage in a safety version in accordance with EN 837-1 (S3) and a valve to prevent fugitive emissions. An easily rotating adapter with a special sealing packing connects the measuring instrument and the valve. The system is fully leak-tested in accordance with the requirements of TA Luft (VDI 2440) for fugitive emissions. The EMICOgauge measures pressures from 0 to 420 bars. In the event of a fault due to high overpressure, the S-3 safety version protects the user from injury. The freely rotating swivel adapter allows 360-deg positioning of the display and easy dismounting of the measuring instrument for calibration. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.de

Compact relay modules for use in hazardous areas

Two new relay modules have been added to this company's product range for hazardous areas in Zone 1. The series 9174 and 9177 (photo) relay modules enable a.c. and d.c. loads to be switched using the Ex e and Ex i types of protection. The compact devices are just 12 mm wide, and only require a suitable field enclosure made of plastic or thin-walled stainless steel. The 9177 enables galvanically isolated switching of intrinsically safe (Ex i) and non-intrinsically safe (Ex e) electrical circuits using an electromechanical relay.

Any combination of both Ex i and Ex e electrical circuits can be connected to the coil and contact connections. This enables a single relay module to be used in up to four operating modes. The 9174 relay module switches electronically, which makes it suitable for applications with frequent switching operations. — *R. Stahl AG, Waldenburg, Germany*
www.r-stahl.com

A cloud-based software service for monitoring waterworks

Netilion Water Networks Insights (NWNI; photo) provides reliable monitoring of flow, pressure, temperature, level, water quality and other measurements. This software service connects all levels of water


Endress+Hauser

supply systems, empowering service providers and water associations to manage multiple control and data sources through a single interface. These sources include field devices, industrial controllers, data transfer components, data recording and archiving devices, analysis and forecasting tools, and others. NWNI provides access to all measurement data gathered in a water network and transmitted to the cloud, whether its users are accessing the system from a control room computer, via a laptop at home, on a tablet in the field, or from a smartphone on the move. The web-based interface provides users with complete system monitoring, and when limit values are exceeded, or in the event of failure, it delivers alarms to users via e-mail, SMS, or push notifications. — *Endress+Hauser, Greenwood, Ind*.
www.us.endress.com

High-shear mixers for fine dispersions and emulsions

Batch high-shear mixers equipped with the Solids/Liquid Injection Manifold (SLIM) Technology (photo) deliver powders in an efficient manner for quick wet-out and complete dispersion into low-viscosity liquids. In


Charles Ross & Son Company

a conventional rotor/stator mixer, materials are continually drawn from below the mixing head and then expelled at high velocity through the stator openings. A SLIM mixer assembly with Progressive Spiral Porting creates a powerful vacuum that draws powders directly into the high shear zone and rapidly disperses individual solid particles into the liquid vehicle. This method of powder addition dramatically reduces the formation of lumps (fisheyes), prevents floating powders, eliminates dusting, and accelerates mixing time, says the manufacturer. The SLIM can also be used to introduce minor liquid components and create fine emulsions. To easily raise and lower the mixer in and out of the mix vessel, a floor-mounted design equipped with an air/oil hydraulic lift is available. Safety limit switches prevent operation of the mixer while in a raised position or without a mix vessel in place. — *Charles Ross & Son Company, Hauppauge, N.Y.*
www.mixers.com

These flow regulators are now available in new sizes

The complete product line of this company's stainless-steel constructed NSF/ANSI 61-certified automatic Flo-Trol valves (photo, p. 30) are now available. The most recent additions to the Flo-Trol flow-regulator line includes 3/8- through 3-in. models, and standard flow range offerings from 0.19 to 120 gal/min. With only one internal controlling mechanism — a Buna-N self-cleaning orifice — Flo-Trol flow regulators provide constant flow over a wide pressure range. Flow-


Flomatic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Alfa Laval

rates are maintained within ±15%, averaging between 15 and 125 psi. Additional specifications include a max pressure of 200 psi and max temperature of 180°F. — *Flomatic Corp., Glenn Falls, N.Y.*
www.flomatic.com

High-purity pressure gage with reed switch

The 50-mm HPS high-purity pressure gage with reed switch (photo) is ultrasonically cleaned to provide exceptional quality and reliability in ultra-high-purity gas delivery systems. The reed-switch capability provides an additional safety feature through actuating an internal switch that triggers an alarm or a process condition change. The gage features stainless-steel construction and wetted components that are ideal for use with industrial gases in semiconductor and electronic manufacturing. It is helium leak tested to 1 × 10^{-8} std. mL^3/s, cleaned in class 10,000 cleanroom and packed in a polyethylene-sealed bag after nitrogen gas flushing. — *Ashcroft Inc., Stratford, Conn.*
www.ashcroft.com

A one-size-fits-all electrolyzer for 'green H_2' production

This company is launching the first standardized electrolyzer suitable for mass production. The EL 4.0 (photo) is a fourth-generation anion-exchange-membrane (AEM) electrolyzer the company has been developed since 2017. The new version is smaller, lighter and ISO 22734 certifiable. The technology combines the benefits of alkaline electrolyzers' low-cost materials (steel instead of titanium) with the flexibility and compact size of proton-exchange-membrane (PEM) electrolyzers. The standardized modules can be stacked and combined for projects of any size — all the way to the megawatt scale. The EL 4.0 has a production rate of 500 NL/h of H_2 with 99.9% purity (99.999% with optional dryer) and a pressure of 35 bars. — *Enapter AG, Berlin, Germany*
www.enapter.com

Benzene monitor for asphalt production and more

The Titan (photo) is a specific fixed gas detector, based on photoionization detection (PID), designed only for the monitoring of benzene. This makes it the perfect choice for use in asphalt manufacturing plants, where benzene is likely to be the most prominent volatile organic compound (VOC) that requires management and monitoring. As a fixed unit, the Titan can be installed at regular distances around sites, and with its "plug and play" installation approach, the Titan can be left monitoring without the need for intervention. Two alarm systems can be set at the user's convenience, and another two are pre-set relays for immediate warnings, so no exposure incident is ever missed. The Titan offers continuous real-time data feedback of VOC concentrations in the air, taking samples every minute to an accuracy of 0.1 parts per million (ppm) or +10%, whichever is greater. — *Ion Science Ltd., Royston, U.K.*
www.ionscience.com

Save up to 95% in CIP liquid with this drain valve cleaner

Drain valves comprise up to 20% of all valves in a typical processing plant. But cleaning them is costly, difficult and time-consuming due to long cleaning cycles and the risk of pressure shocks. The new ThinkTop pulse seat clean (photo) addresses all these issues, quickly and effectively cleaning drain valves while delivering savings of up to 95% in cleaning-in-place (CIP) liquid, says the company. Short bursts, or pulses, drive the valve cleaning process, activating the valve when shear forces peak. Each position-based pulse takes less than a second, preventing pressure shocks in the system. The pulse creates high turbulent flow as the liquid passes through the narrow gap between the valve house and valve seat, effectively removing all residuals for spotless drain valves. Intended for use with single-seat valves or butterfly valves used as drain valves, pulse seat clean is a standard feature of ThinkTop V50 and V70 sensing and control units with one solenoid valve. — *Alfa Laval AB, Lund, Sweden*
www.alfalaval.com

A filter to recover and recycle valuable battery chemicals

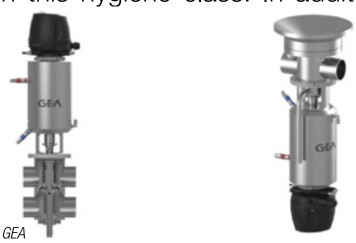
Launched last month, the energy- and water-efficient AC (activated car-

Metso Outotec

bon) filter responds to the market's increasing demand for advanced and sustainable battery-metals processing technologies. The modular AC filtration technology (photo) is designed for smaller side streams of copper and other metal-loaded aqueous streams. It is specifically suited for efficient organics removal before the electrowinning and crystallization processes. The AC filter utilizes the already proven design and operation philosophy of the company's DM filter product family and is suitable for both greenfield and brownfield installations. Benefits of the AC filter include: increased end-product yield and quality; increased recovery and recycling of valuable process chemicals; low energy consumption, due to low pumping pressure; and minimized water consumption with optimized back washing. — *Metso Outotec Corp., Helsinki, Finland*
www.mogroup.com

Leakage valve boosts safety of ESL production

The Aseptomag LV leakage valve is a mixproof double-seat valve is designed for manufacturers of foods and beverages, as well as pharmaceutical products. Typical examples are products with an extended shelf life (ESL), such as soft drinks, fruit juices and milk-based and lactic-acid fermented products, along with plant-based alternatives sold chilled by retailers. The design features significantly mitigate the risk of contamination in this hygiene class. In addition,



GEA

products become more durable — with less preservatives. Thanks to its dimensions, the compact double-seat valve for ESL processes takes up less space and is easier to install and maintain than aseptic alternatives. Technical features, such as the backstroke barrier, can be easily retrofitted without the need to replace the actuator or other existing equipment. The leakage valve is available in the upright LV version for typical valve matrices (photo, left) and in the LVBS version (right) for tank bottoms. The latter is typically used for tank installations and can also be connected to a pigging station for resource-saving product recovery systems. — *GEA Group, Düsseldorf, Germany*
www.gea.com

This fast coupling device is patent-pending

REconnect (photo) is a new a coupling device for simple and safe decoupling and recoupling of diaphragm seal systems, including process connections and measuring devices. REconnect consists of two parts — one fitted to the measuring device, the other to the process connection – and with the aid of the special lock, they are easily separated. The lock is detachable and can be retained separately so that REconnect cannot be operated accidentally or by unauthorized persons. After separation, the two parts of the coupling are each closed with covers made of stainless steel to protect the measuring instrument and diaphragm seal. The fast coupling is vacuum-proof and has no parts that can be lost. It is suitable for applications in the pharmaceutical, food and chemical industries. — *Labom Mess- und Regeltechnik GmbH, Hude, Germany*

www.labom.com ■

Gerald Ondrey

Predictive Maintenance Methods

Department Editor: Scott Jenkins

Predictive maintenance (PdM) programs can provide advanced warning of equipment problems and potential failures. This one-page reference provides brief descriptions of six common predictive maintenance methods.

Infrared thermography

Continuous monitoring of equipment temperature over time has the potential to identify both normal and abnormal temperature profiles. Running equipment at elevated temperatures diminishes lifetime, and is an early symptom of equipment damage or malfunction. For example, heat generated from friction in mechanical equipment or heat from electrical resistance in electrical components can be precursors to larger problems.

Infrared (IR) thermography instruments use a special camera to detect IR electromagnetic radiation that is emitted from equipment surfaces. Higher-temperature areas emit more IR radiation. A lens in the camera focuses the IR radiation onto a thermal sensor. Different pixel configurations in the sensor determine the resolution of the camera. The IR energy is converted into a visual image in which pixels are color-coded according to temperature, and a "heat map" of the object is generated (Figure 1). IR thermography can be used to monitor bearing temperature, identify deteriorating or overloaded circuits, analyze process temperature and detect leaks.

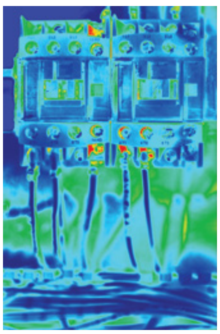


FIGURE 1. Infrared thermography uses infrared radiation from surfaces to make a heat map

Ultrasound analysis

Many failure conditions and damage processes tend to produce detectable levels of ultrasound before they are severe enough to be audible to humans. These processes include pressure leaks (of compressed air or steam, for example), electrical discharge and deterioration of bearings and other machinery. Ultrasonic equipment detects airborne and structure-borne sounds that are normally inaudible to the human ear and electronically "transposes" them into audible signals that a technician can hear and view on a display. Ultrasound technology can detect certain mechanical and electrical faults by sensing subtle changes in ultrasonic amplitude. For example, ultrasound is adept at finding early-stage bearing faults.

Motor-current signature

Developing faults can cause distortions in the current drawn by an electric motor. Motor-current-signature analysis (MCSA) detects impending problems by measuring the current drawn by the motor and analyzing distortions to the current's waveform. Analyzing a frequency spectrum of the current waveform can reveal distortions that appear as peaks on a frequency spectrum, located at frequencies that are characteristic of the phenomenon causing the distortion. By assessing the size of the peak and its frequency, users can deduce the probable cause of the distortion and assess its severity. MCSA can be used to detect developing defects in rotors, such as rotor bar cracking.

Oil analysis

Contamination can hinder the ability of machinery lubricants to perform their required task. When that occurs, machinery components can wear quickly and equipment surfaces can degrade, contributing to machinery failures. Oil analysis monitors and analyzes lubricant oils for characteristics such as contamination, chemical content and viscosity. An understanding of changing lubricant properties can increase both uptime and extend the lifetime of equipment.

Partial discharge monitoring

Partial discharges (PD) are small electrical sparks that do not completely bridge the electrodes. They occur within the electrical insulation of medium- and high-voltage electrical assets, such as cables, transformers, switchgears and windings found in large motors. Discharges are the result of an electrical breakdown of an air pocket within the insulation, and give off energy in different forms, which can be detected by sensors. Partial discharges are an early indicator of insulation deterioration.

FIGURE 2. Vibration analysis uses data on the vibration signature along three axes

Vibration analysis

Vibration analysis monitors the vibratory signature of a system over time and looks for anomalies to the established pattern (Figure 2). Machine-mounted accelerometers gather data about the vibration signature along three axes (vertical, horizontal and axial) and quantify the magnitude of the vibration in terms of displacement (total distance moved by vibrating part), velocity (speed of the vibrating mass) and acceleration (rate at which velocity is changing).

Machine vibration comes from many sources, and even small amplitudes can have severe effects on the overall machine vibration, depending on the transfer function, damping and resonances. ■

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Production of EPDM Rubber

By Intratec Solutions

Ethylene propylene diene monomer (EPDM) rubber is a terpolymer elastomer derived from ethylene and propylene, along with small amounts of a non-conjugated diene as a third monomer (Figure 1). With a completely saturated polymer backbone, this random elastomeric copolymer exhibits interesting properties, including excellent weathering stability and heat resistance, good insulating properties as well as good resistance to chemicals, moisture and steam.

EPDM has excellent ozone resistance compared to natural rubber and its synthetic substitutes, such as styrene-butadiene rubber, butadiene rubber and isoprene rubber. These features make EPDM a versatile synthetic rubber, with several applications in the automotive industry, in the construction industry and as a plastic modifier.

Commercial-scale production of EPDM rubber is mainly based on solution and suspension polymerization processes, and the polymerization conditions determine the structure of the final product obtained. Different products vary mainly according to their ethylene-to-proplyene ratio, monomer sequence distribution, molar mass and molar mass distribution, as well as by the content and type of the diene used. In this context, EPDM rubbers are produced in different grades by each manufacturer according to the specialty applications targeted, in such a way that it is not standardized in the way that general-purpose rubbers are.

The ethylene percentage of EPDM products can vary between 15 and 85%. It may be produced in different physical forms, from solid to friable bales, pellets and granular forms and oil blends.

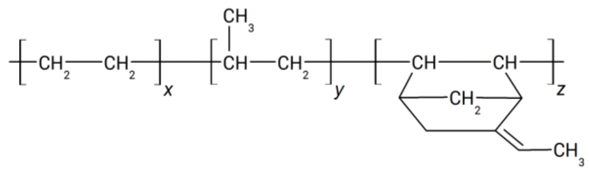

FIGURE 1. EPDM rubber is a random copolymer of ethylene and propylene, with a diene (norbornene, in this case) added as a third monomer

The process

EPDM rubber production from polymer-grade (PG) propylene and ethylene comprises three major sections: (1) polymerization; (2) purification; and (3) finishing (Figure 2).

Polymerization. Initially, the monomers are treated and mixed and the mixture is continuously supplied to a stirred, jacketed reactor, as well as a solution containing the catalysts. The reaction occurs substantially in the liquid phase, with an excess of liquid propylene, which is used as a diluent. The rate of polymerization is controlled by the rate of catalyst addition, while temperature control is readily accomplished by controlled evaporation of the propylene. As the polymer is formed, it precipitates out of the reaction medium.

Purification. The slurry is pumped into a vessel, where reaction is terminated and the slurry is mixed with small amounts of toluene and water. The toluene allows the water to extract the catalyst entrained in the polymer. Subsequently, unreacted monomers and solvent are removed from the catalyst-free polymer slurry in steam strippers containing water as dispersing medium, and are recycled to the polymerization reactor.

Finishing. The rubber polymer, present in the form of wet crumbs in water, is fed to a drum with auxiliary agents, such as an anti-agglomerant, so as to ensure that copolymer particles stay suspended and show a reduced tendency to agglomerate. The crumb slurry, with moisture content as high as 90 wt.%, is then pumped to a rotary screen, where most of the free water is removed. The wet polymer is conveyed through a single screw extruder. While being conveyed through the extruder, water is expelled from the polymer. The extruded dried crumb, containing less than 0.5 wt.% water, is cooled down, baled and packed.

Uses and pathways

EPDM is widely used across several market segments, including automotive applications, where it can be found in weather stripping, hoses, tubing, brake components, isolators, mounts and grommets. EPDM is also found in plastics, such as in impact-modified polypropylene and thermoplastic olefins, as well as in construction, such as in roofing membrane, glass sealers, gaskets and tapes. Other industrial applications for EPDM include O-rings, mounts, cable jacketing, insulation, cable filler, connectors, footwear, and carpet underlayment. ■

Editor's note: The content for this column is developed by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are based on publicly available and non-confidential information. The content represents the opinions of Intratec only.

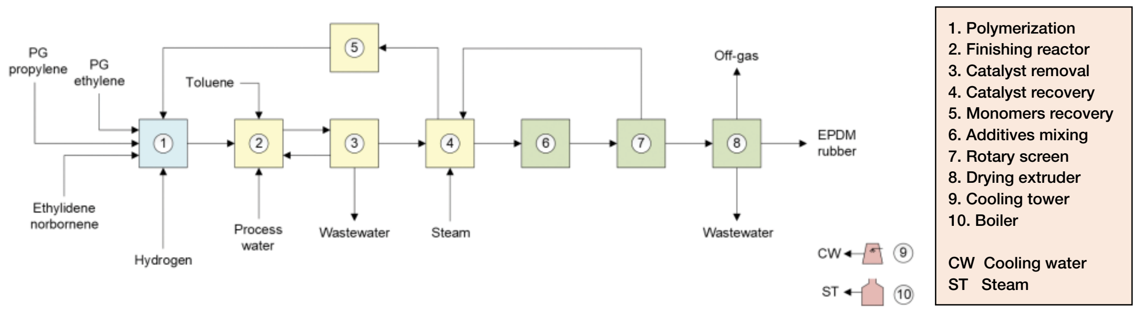

FIGURE 2. The diagram shows the polymerization process for making EPDM rubber

Controlling Particle Characteristics with Agglomeration

Solids-handling processes and downstream process steps can benefit greatly from carefully controlled particle characteristics. Presented here is guidance on how agitation agglomeration techniques can achieve desired particle properties

Carrie Carlson and Chris Kozicki
FEECO International

IN BRIEF

Throughout the diverse sectors of the chemical process industries (CPI), the ability to control the particle characteristics of bulk solids is crucial. Controlling particle characteristics allows producers to manage product performance, ensure shelf life, regulate downstream processes and more. One technique that is especially useful in controlling particle characteristics is agglomeration (particle size enlargement), which converts powders and fines into granules. There are several different forms of agglomeration — some that utilize extreme pressure to form agglomerates, others that use heat, and so on. Agitation agglomeration utilizes motion, typically along with a liquid binder, to form granules. This technique is also sometimes referred to as wet granulation, pelletizing, or tumble-growth agglomeration. The flexible nature of the agitation agglomeration approach allows producers to achieve a specific set of desired particle characteristics.

This article provides information on why controlling particle characteristics is so essential, which particle characteristics can be controlled through agglomeration, and how the various types of agitation agglomeration equipment provide the opportunity to reach the sought-after specifications.

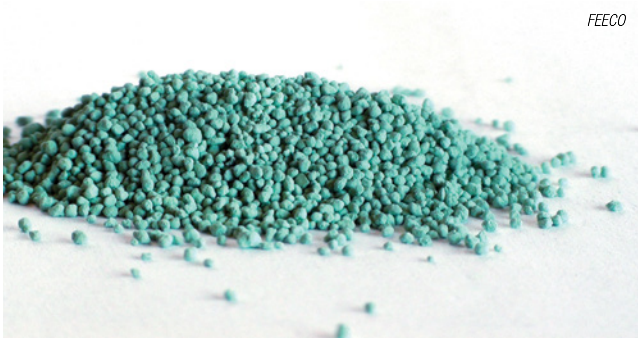

FIGURE 1. Paint pigment micropellets, such as the ones shown here, were produced in a pin mixer, and are an example of how particle characteristics can impact desired product qualities

Particle engineering benefits

Chemical producers can use particle characteristics both as a tool in the production line, as well as a way to manage the quality and performance of their finished (or intermediate) product (Figure 1). In each case, their ability to control these parameters is essential in meeting market demands and being able to do so efficiently.

Particle characteristics in the production line. From catalysts and fertilizers, to specialty chemicals, fillers and more, particle characteristics are often the foundation of every step in a production line. By controlling them, producers can improve flowability and precisely control metering and dosing of process components, allowing them to ensure that products meet a guaranteed analysis, or have the precise chemical composition needed to do their job. Further, particle characteristics can be used to make handling and transporting the material around a facility cleaner and less dusty, minimizing the amount of raw material or product lost to dust. The ability to control particle characteristics also goes beyond the initial production line by allowing producers to control how the solids perform in downstream processes, such as in the smelting process, where particle characteristics are used to promote enhanced gas-solid heat transfer.

Particle characteristics in the product. In an intermediate or finished product, particle parameters are used to reduce shipping

FIGURE 2. Limestone powder (left) can be agglomerated into limestone pellets (right), thereby affecting solids qualities such as flowability, dissolution, particle attrition and more

FIGURE 3. Pin mixers, like the one shown here, have a shaft fitted with rods that rotates within a trough

costs, improve storage characteristics, and most importantly, meet the precise expectations of the end user. These expectations might include one or more of the following:

- Preventing segregation of the solid product during transport and storage
- Ensuring that products arrive to customers in the exact condition desired
- Mitigating the potential for caking during shipping, storage or on store shelves
- Optimizing the look, feel and performance of the product for its intended application
- Minimizing the amount of particle attrition a product experiences, thereby reducing the amount of product lost as dust and fines
- Ensuring that end products meet the demands of their intended application

In the hydraulic fracturing industry, for example, crude oil producers require solid proppant materials that meet certain specifications in composition, shape and compression strength to hold open rock fissures and allow for efficient hydrocarbon recovery. If producers of proppants were unable to control product parameters, hydraulic fracturing would be much less efficient.

Particle parameters

The particle characteristics that are important in any given setting vary based on the specific industry sector, the nature of the product, and the individual manufacturer. Even within a single plant, the same product is often manufactured in differing qualities and grades, making it essential for producers to be able to meet the different characteristics expected of each product line. Agitation agglomeration allows producers to target the specific set of parameters important to them.

Typical parameters that are desirable to control include the following:

- Uniformity index (UI) and size guide number (SGN; the average particle diameter)
- Bulk density
- Particle size distribution (PSD)
- Crush strength
- Moisture content
- Green/wet strength
- Particle shape
- Surface quality
- Porosity

By controlling these parameters, producers are further able to manage solids qualities such as the following (Figure 2):

- Flowability
- Rheology
- Dissolution
- Solubility
- Surface-area-to-volume ratio
- Melting abilities
- Particle attrition

The agitation agglomeration process is also flexible in that it allows for various solid and liquid additives to be included, giving producers control over formulation as well.

Equipment

Agitation agglomeration can be carried out using different types of equipment. Depending on the specific goals of an application, the different types of equipment may be used alone, or in combination, to produce the desired results. Typically, the combinations consist of one mixer and either a disc pelletizer or rotary drum. Each type of equipment, and each combination, has the ability to manipulate a unique set of process variables in reaching the desired product characteristics. An overview of the most common types of agitation agglomeration equipment, along with the unique adjustable variables for each, is given below.

Pin mixer. The pin mixer (Figure 3) is a horizontal mixer consisting of a single shaft in a trough. The shaft is fitted with an arrangement of rods or "pins" that, upon rotation, create an intense spinning action inside the trough. This thoroughly mixes solid and liquid feed components into a homogeneous mixture.

As the material moves along the length of the mixer, this spinning creates a rolling action among particles that facilitates the formation of small, dense seed pellets, or "nuclei," which may meet the desired granule specifications, or may move on to another piece of equipment for further growth and refinement. Because this process produces small agglomerates, it is often referred to as "micro pelletizing."

The following variables are adjustable on the pin mixer and can be manipulated to control the particle characteristics of the material exiting the mixer.

- Retention time (the amount of time the material is processed in the unit): In the pin mixer, a longer retention time generally equates to more dense agglomerates.
- Binder spray location(s): In all equipment, binder spray placement is used to encourage more or less wetting of fines, granule formation, and growth.
- Binder and feed rates: For all types of equipment, the rates at which binder and feedstock are continuously fed to the unit generally follow capacity require-

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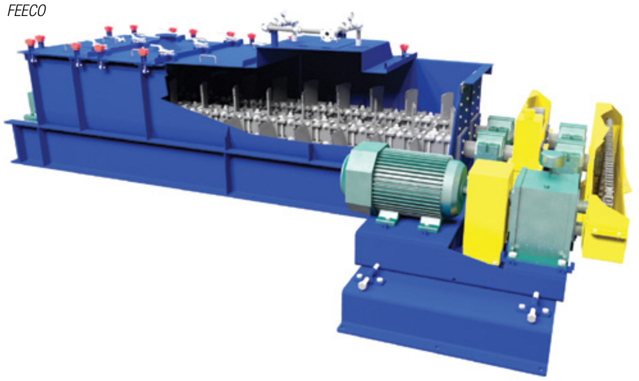

FIGURE 4. **Pugmill mixers, like the one shown here, have two shafts rotating counter-currently relative to each other**

ments, but in some cases, may require some adjustment to reach the desired characteristics.

- Spray-nozzle type: Spray nozzles are available in a variety of designs, producing everything from drips and streams, to atomized sprays. In all types of equipment, the nozzle type is chosen in combination with the number and location of binder sprays to control the wetting of fines, as well as granule formation and growth
- RPMs/speed of shaft: In the pin mixer, shaft rotational speed can be used to encourage additional densification without the use of additional binder
- Pin arrangement: Pin arrangement refers to the number and placement pattern of pins around the shaft. For example, pins can be positioned in a helical pattern to help move material through the mixer, or they can be arranged for full- or half-sweep, among other patterns

Pugmill mixer. The pugmill mixer, also known as a paddle mixer or pug mill (Figure 4), is also a horizontal mixer. Instead of a single shaft, as in the pin mixer, the pugmill mixer has two shafts that rotate counter-currently to each other in a U-shaped trough. Each shaft is fitted with several paddles. This type of mixer also produces a homogeneous mixture of solid and liquid feed components, but instead of a spinning action, it uses motion comparable to kneading and folding. This produces some agglomerates of varying size, and is often referred to as "conditioning" for its role in de-dusting material fines via wetting and mixing.

The following variables are adjustable on the pugmill mixer, and can be manipulated to control the outcome of the material exiting the mixer:

- Retention time: Inside a pugmill mixer, a longer retention time typically leads to more agglomerates
- Binder spray location(s)
- Binder and feed rates
- Spray nozzle type
- RPMs (rotational speed of shafts): The shaft rotation speed in a pugmill mixer can be used to encourage more vigorous mixing, as well as more agglomeration
- Paddle arrangement: Paddle arrangement, along with shaft speed, can be adjusted to intensify mixing action, as well as to modify retention time

Disc pelletizer (pan granulator). The disc pelletizer, or pan granulator (Figure 5), consists of a rotating disc mounted onto a stationary base. Binder and feedstock are continuously fed onto the disc. Fines (or seed pellets if a pin mixer precedes the disc) are carried up the side of the disc and cascaded down through the feed stream. Combined with the moisture from the binder, this causes the fines to become tacky and pick up additional fines. The rolling motion forms the aggregated fines into pellets.

Pellets continue to pick up moisture and fines as they move around the disc, growing in a layering effect known as coalescence. Once pellets reach the desired size, they are discharged from the disc via centrifugal force.

The following variables are adjustable for disc pelletizers and can be manipulated to control the outcome of the material exiting the disc:

- Retention time: In a disc pelletizer, longer retention times typically lead to larger agglomerates.
- Binder spray location(s)
- Binder and feed rates
- Spray nozzle type
- Placement of feed location: Feed placement, in collaboration with binder spray locations, can encourage increased or decreased granule formation.
- Disc speed and angle: Because the disc pelletizer relies on centrifugal force to carry granules around the disc, disc speed and angle are often adjusted in collaboration to create the desired amount of centrifugal force and are therefore closely related.

Rotary drum (granulation drum). The rotary drum, also known as an agglomeration or granulation drum, is a large, rotating cylinder set on a slight angle, which helps to convey material through the unit (Figure 6). Material may be fed into one end of the unit, or at multiple locations throughout the drum, and binder is sprayed onto the material bed. The rotation imparts a rolling and tumbling motion that causes coales-

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FIGURE 5. **This photo depicts a disc pelletizer, showing the rotating disc mounted onto a stationary base**

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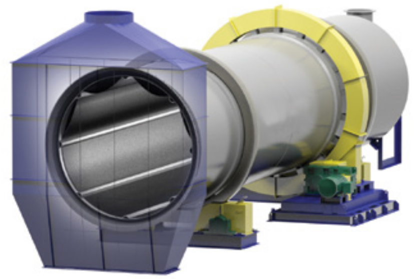

FIGURE 6. **Rotary drums are angled to help convey material through the equipment as it rotates**

FIGURE 7. Testing is often required to determine the combination of equipment and process variables that will result in the desired solids properties

FIGURE 8. When feedstock varies, processors can modify the agitation agglomeration process to maintain product quality

cence. Tumbling flights can be used to assist in agitating the material bed.

The following variables are adjustable on the rotary drum and can be manipulated to control the outcome of the material exiting the drum:

- Retention time: In a rotary drum, a longer retention time typically leads to more polished agglomerates, due to the continued tumbling action.
- Binder spray location(s)
- Binder and feed rates
- Spray nozzle type
- Drum speed: The drum speed can be used to increase the rolling action imparted on the fines.

Drum speed, in combination with feed rate and binder spray locations, can be used to encourage more vigorous tumbling of the bed to better distribute the binder.

Evaluating equipment

The different possible combinations of equipment and process variables, as well as the variation in the starting feedstock, can make it difficult to predict the combination of parameters that will produce the desired results. This often requires a thorough testing program to determine the right combination of variables (Figure 7).

An understanding of agitation agglomeration fundamentals and the nuances behind each type of equipment helps to expedite this process, as the various physical and chemical parameters of the starting feedstock, along with the desired end product characteristics, can help to inform on the most appropriate equipment configuration. For example, the desire for highly refined granules often favors the pin mixer-disc pelletizer combination, in which the pin mixer yields a thorough mixture of material and begins forming seed pellets that can then further be grown on the disc pelletizer.

In contrast, if the priority is wetting and the formation of only rough agglomerates, a pugmill mixer may best serve the purpose. If the operation requires slightly more refined granules, but will be operating at a higher capacity, a rotary drum may be added after the pugmill mixer to achieve the desired results.

Because each material responds uniquely to agitation agglomeration, testing programs such as those sometimes offered by equipment vendors are often a critical part of developing a successful operation.

Adjustments during production

While process variables must be defined in a new process, in an already existing process, it is sometimes necessary to make adjustments in order to maintain product quality.

When process or feedstock conditions fluctuate, the agitation agglomeration process allows operators to respond as needed, modifying the variables mentioned above to re-stabilize the process (Figure 8).

For example, if the feedstock coming in suddenly has a lower moisture content, operators may need to adjust the binder spray rate to maintain the liquid-to-solid ratio. Or, if a pin mixer is in use, the operator may choose to increase retention time in the mixer to maintain the same density of the granules exiting the mixer. Making these types of adjustments can be challenging, as the adjustment of one variable often influences other variables.

For this reason, training operators on the key principles behind an operation is essential to maintaining product quality, minimizing downtime and product loss, and meeting production schedules.

Concluding remarks

For chemical producers, control over particle characteristics is vital to the ability to meet product specifications, streamline processing operations, and operate efficiently. Agitation agglomeration technology can be a powerful tool in helping producers to make granular products according to exacting specifications. However, with the many different types and combinations of equipment, process development testing and operator training are critical to reaching a product with the desired results. Further, consulting a pelletizing or agitation agglomeration expert can also provide the necessary guidance. ■

Edited by Scott Jenkins

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Refining Powder-Testing Practices

A rigorous and structured approach to determining the potential value of powder testing techniques in solids-handling applications can improve powder characterization and processing

Jamie Clayton
Freeman Technology

IN BRIEF

DRIVERS FOR CHANGE

THE EVOLUTION OF POWDER TESTING

CASE STUDY 1

CASE STUDY 2

THE WAY AHEAD

Many chemical process industries (CPI) sectors face growing pressure to measure and control powder properties more effectively, either to improve manufacturing efficiency — from raw material selection, through processing to quality control — or to gain a competitive edge via superior product performance. At the same time, there is growing pressure to streamline the analytical processes that are used to drive progress. Identifying the most informative techniques for powder testing and measurement is becoming increasingly critical, whether to help develop innovative technology or to simply remain competitive in given markets.

This article considers commercial drivers for adopting or reviewing powder testing techniques with the aim of identifying optimal solutions from a growing range of test options. Experimental studies compare the performance of different techniques in applications from the pharmaceutical and cosmetics industries. The results illustrate the benefit of a rigorous and structured approach to deciding which powder properties to measure, and the potential value of a robust strategy for powder characterization.

Drivers for change

Competition drives a cycle of continuous improvement, across industries and in many leading companies. Competitors may begin manufacturing a more reliable product, or one that more effectively meets application requirements, or they may develop the ability to simply sell products at a lower price due to reduced manufacturing costs. The response to these stimuli is to re-evaluate current practices and make plans to improve.

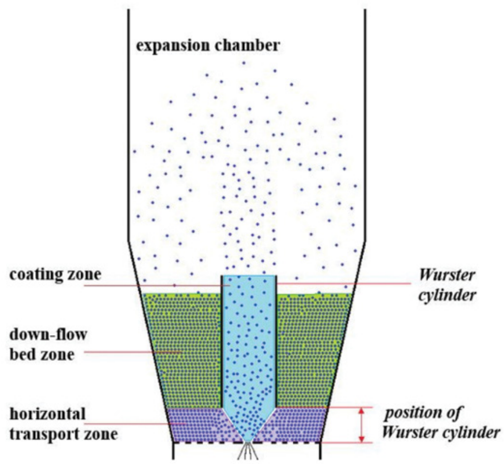

FIGURE 1. As discussed in Case Study 1, a Wurster fluid-bed coater subjects the powder to fluidization in the cylinder, confined flow in the down-flow zone and partially aerated flow in the horizontal transport zone

Analytical services — either conducted in-house or outsourced — contribute significantly to the cost of research and development (R&D), product commercialization, and routine manufacture, and are often a target for cost-cutting or transformation. A periodic reassessment of which analytical techniques are being applied, as well as the value of the information they deliver, and the effort involved in its generation is a sound business practice, particularly against a backdrop of innovation in analytical instrumentation.

Powder processors face unique challenges when it comes to refining analytical practice. The properties that define the performance of liquids and gases are well-understood and easily measured, and established design methodologies for processing equipment help to identify relevant parameters. This is not the case for powders. Powders

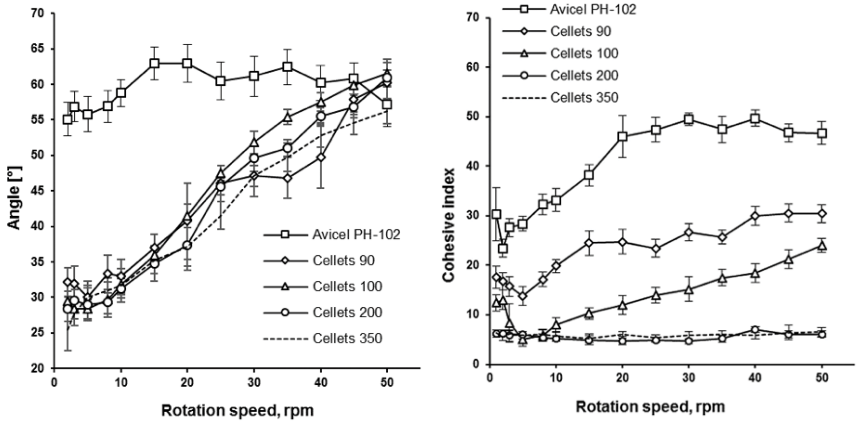

FIGURE 2. The graphs show data on angle of repose (left) and cohesive index (right) from the avalanche tester for Cellets samples and Avicel PH-102 discussed in Case Study 1

are assemblies of solid particles, low levels of liquid, and gas (usually air) that exhibit complex behaviour resulting from interactions between these phases. The analytical techniques routinely applied to powders can be classified as measuring either particle or bulk powder properties. Particle parameters include size and shape, density, surface area, porosity and surface charge. All of these parameters may justify measurement, depending on the product and its intended application. However, measuring particle properties alone does not enable reliable characterization of the bulk powder. Notably, particle properties often do not permit full characterization of flowability, often a critical property for solids-processing operations.

Uncertainty around the optimization of bulk-powder testing techniques is common, particularly for new or demanding applications. Bulk density is a routine measurement that defines the size-weight relationship of packaged products and impacts the throughput of transportation systems. But if bulk

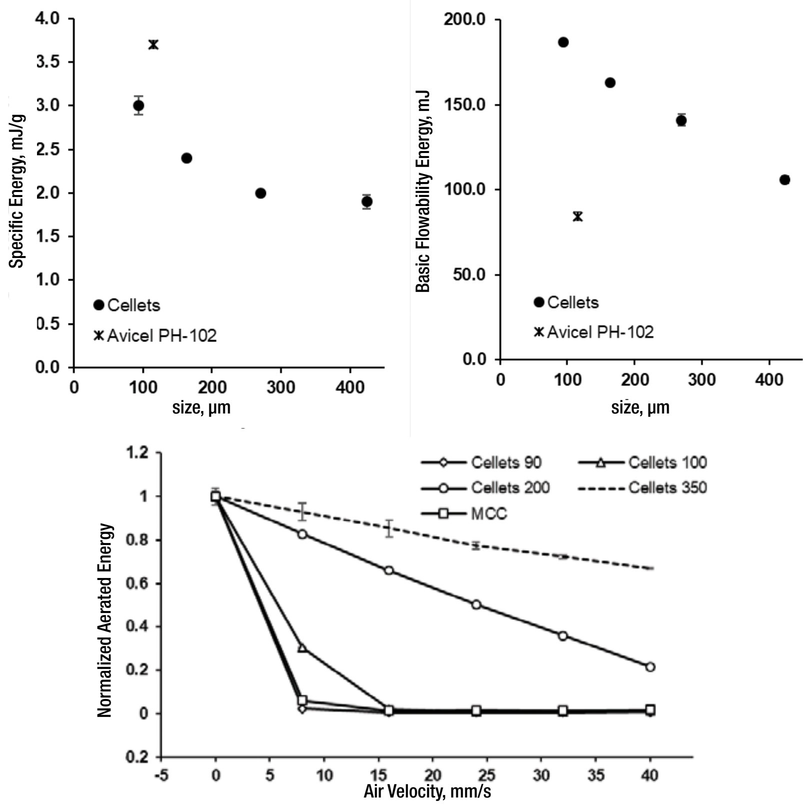

FIGURE 3. The graphs show flow-energy measurements — specific energy (left), basic flowability energy (middle) and normalized aerated energy (right) — for Cellets and Avicel PH102 samples in Case Study 1

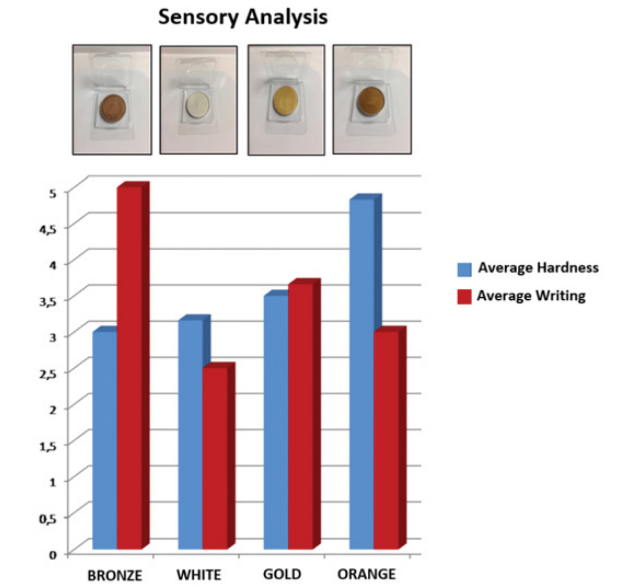

FIGURE 4. The graph shows data from a sensory analysis of the hardness and writing performance of cosmetic formulations containing different pigments, as discussed in Case Study 2

density and particle properties in isolation do not adequately describe performance — and they rarely do — what other techniques should be considered? Few other bulk powder properties appear consistently on product specifications, and design methodologies for powder processing equipment are extremely limited. Hopper design is the exception, and points to the value of shear-cell testing. However, even those adept at shear-cell analysis are increasingly aware of its limitations. This raises the question of how to best identify a powder testing regime that can provide the information needed to compete effectively.

The evolution of powder testing

Commercial powder testers vary considerably on the basis of three key characteristics:

Ease of use/productivity. How easy is it to generate high-quality data? How much time is required for the measurement? What level of training and expertise is required for instrument use?

Sensitivity. What is the ability to differentiate among similar samples? Repeatability and reproducibility have an impact on sensitivity, but some techniques are inherently more sensitive than others.

Relevance. How well does the powder-property information generated with a given analytical device correlate with the aspects of powder behavior or process performance that are of greatest interest?

An optimal analytical solution will generate sufficiently sensitive and relevant data with the minimal level of manual input.

Current practice and trends in the application of powder testing are driven not only by the need for better, more informative data, but also by growing appreciation of the economic returns that modern instrumentation can deliver. An enhanced ability to efficiently handle the large amounts of data that modern testers can generate has been instrumental in revealing this value.

Traditional powder testing techniques — as exemplified by angle of repose, flow through an orifice and tapped density methods — generate a single descriptor of flowability. If this is not informative with respect to the behavior of interest, then the tester has no value. If it is informative, then the tester potentially has value, though poor repeatability and sensitivity can be a crucial limitation when it comes to differentiating similar powders. Either way, there are limited amounts of data to interrogate.

Alternative options for powder testing include avalanche or rotating-drum testers, which capture images of the interface of a powder sample as it tumbles within a drum rotating at different speeds. In this environment, powders exhibit a periodic flow pattern, initially moving with the rotating drum before reaching a certain height at which the surface breaks and the powder falls, or avalanches, and flow establishes. This cyclical behavior is repeated over and over as the drum rotates. Mathematical analyses of the captured images generate a number of parameters, but it is important to recognize that they are all derived from the application of a single technique, as with traditional methods. Furthermore, avalanche testing offers a limited scope to modify the test conditions to simulate a specific process. Drum speed is the primary test variable.

In contrast, dynamic powder testers that measure flow energy values quantify powder behavior under a range of different stress and flow regimes of direct relevance to powder processes. Flow energy is generated from measurements of the forces acting on the blade of the tester as it rotates through a powder sample, which can be in a consolidated, conditioned, aerated or fluidized state. Testers with this capability also offer shear and bulk property measurement, combining three distinctly different testing techniques to generate multiple parameters that provide multi-faceted characterization for a given powder.

With the limitations of single-number analysis now widely recognized, and with advances in data analysis software making it much easier to efficiently interrogate large datasets, the potential of modern testers is becoming increasingly apparent, and easier to exploit. Applying a broad range of analytical techniques to generate an array of parameters, which are then refined on the basis of their ability to sensitively and

TABLE 1. DATA FOR EXCIPIENTS: PARTICLE SIZE, TOPPED DENSITY AND MASS FLOWRATE

Excipients	Particle size distribution (PSD)		Hausner ratio	Mass flowrate, g/s	
	D50, um	Span		Av	SD
Avicel PH-102	115	1.85	1.21	No flow	-
Cellets 90	94	0.44	1.09	1.76	0.09
Cellets 100	163	0.27	1.09	2.06	0.01
Cellets 200	270	0.34	1.11	1.89	0.01
Cellets 350	424	0.22	1.10	1.83	0.01

TABLE 2 . AVALANCHE TEST DATA FOR THREE PEARLESCENT COSMETIC PIGMENTS

Critical measurements	Bronze	White	Gold
S-L ratio	0.30	0.25	0.32
Avalanche energy, kJ/kg	26.8 ± 26.7	20.0 ± 15.7	35.7 ± 35.5
Break energy, kJ/kg	82.0 ± 17.9	79.5 ± 8.2	104.1 ± 24.0
Hurst index	0.296	0.525	0.803
Rest angle, deg	45.2	45.4	46.1
Surface fractal	4.49	2.92	5.14

relevantly differentiate materials, is increasingly common [*1, 2*]. This approach is highly effective in identifying which powder testers will provide a return on investment by delivering unique and valuable information.

Case study 1

This example involves characterizing the processability of innovative pharmaceutical excipients. A relatively recent innovation in the field of pharmaceutical excipients is the introduction of microcrystalline cellulose (MCC) in the form of spherical pellets, such as Cellets. Coating these inert, neutral, starter cores produces optimized particles for combinatory and controlled-release tablets. A Wurster fluid-bed coater is a popular choice for this process (Figure 1).

In an experimental study, the properties of Cellets of different sizes were investigated using a range of methods. Ref. 3 contains full experimental details. Here, the focus is specifically on the measurements carried out to investigate flowability, which included tapped-density and flow-through-an-orifice testing (JV1000 and Flowability Tester Model BEP2, respectively, both Copley Scientific, U.K.), avalanche testing (GranuDrum, GranuTools sprl, Belgium) and flow-energy measurement (FT4 Powder Rheometer). Data were gathered for Avicel PH102 (MCC powder) for comparative purposes. The aim was to determine a) whether the materials could be differentiated and b) whether test conditions and results could be linked to likely bulk-solids behavior in different regions of the coater.

Particle-size data for the Cellets samples are shown in Table 1, along with the results from tapped-density and flow-through-an-orifice tests. Tapped-density data are presented in the form of Hausner Ratio (HR), the ratio of tapped to poured powder density, and provide no differentiation of the Cellets samples. Differences are observed, however, in the Avicel PH102, which has an HR of 1.21, indicating a classification of "fair" flowability, relative to the "excellent" flow of the Cellets samples (HR in the range 1.09 to 1.11). Flow-through-an-orifice data only provide limited differentiation of the Cellets, particularly when standard deviation values are taken into account, and there is no clear trend — the poorer flowability of the Avicel PH102 is only identified by a "no flow" result.

The avalanche tester reports two parameters: dynamic angle of repose; and cohesive Index (Figure 2). Dynamic-angle-of-repose data exhibit significant variability and, as with the preceding techniques, fail to differentiate the Cellets samples, though Avicel PH102 is again classified as behaving differently. Cohesive index provides some differentiation, but not between the Cellets 200 and 350 samples. Cohesive index is a measure of the extent to which individual flow-angle measurements deviate from the average over the course of the test. The test is essentially a measure of variance, with higher values associated with more cohesive powders.

The avalanching data show varying trends with respect to drum rotation speed. For example, dynamic angle of repose increases with rotation speed for all the Cellets samples, but is relatively consistent for the Avicel PH102, particularly at higher rotation speeds. With respect to cohesive index, the Cellets

TABLE 3. DYNAMIC, SHEAR AND BULK PROPERTIES FOR PIGMENTS

Critical measurements	Orange	Bronze
Basic flowability energy, mJ	507 (±0.8%)	300 (±3.2%)
Specific energy, mJ/g	9.71 (±0.78%)	5.98 (±0.9%)
Conditioned bulk density, g/mL	0.373 (±2.5%)	0.445 (1.1%)
Stability index, mJ	1.12 (±1.1%)	1.01 (±2.2%)
Aerated energy, mJ	195 (±1.1%)	61.2 (±0.4%)
Aeration ratio	2.37 (±3.5%)	4.8 (±2.2%)
Compressibility, kPa	34.8 (±0.9%) kPa	28.0 (±2.1%) kPa
Pressure drop, mBar	31.4 (±0.4%)	54.7 (±1.6%)
Flow function	8.16	18.8

90 sample appears to be plateauing at higher rotation speeds, while the Cellets 100 exhibits an essentially linear response, suggesting that the two samples could generate equivalent values at higher rotation speeds. These results illustrate the extent to which avalanching behavior is influenced by the speed of rotation of the drum, as well as the characteristics of the powder. This complicates the setting of test conditions, and there is little information in the literature correlating avalanching parameters with process performance, to guide this process. In conclusion, it is difficult to infer from these data how the Cellets might behave in different areas of the coater.

Figure 3 shows how flow-energy parameters for the samples — specific energy (SE), basic flowability energy (BFE) and normalized aerated energy (NAE) — differentiate all four of the Cellets samples, exhibiting clear trends with Cellets size. The Avicel PH102 is also differentiated.

In an SE measurement, which involves testing with an upward traverse of the instrument blade, the sample is in a low-stress, conditioned state and is subject to gravitational forces. SE values tend to be primarily influenced by mechanical interlocking and frictional interactions between particles. The reduction in SE with increasing particle size can therefore be rationalized by the fact that larger particles have lower specific surface area, and by the presence of fewer particles in samples of comparable volume. Both factors reduce the extent of inter-particular interactions and, in combination, rationalize the trend observed. The higher SE value of the Avicel PH102 is consistent with this rationale.

In contrast, BFE measurements are generated with a downward traverse of the blade, subjecting the powder to forced or compressive flow conditions. BFE measurements are influenced by a wide range of factors, but the trend in the Cellets data reflects that of the SE data. The Avicel PH102 has a lower BFE value than all of the Cellets, which is due to the fact that more cohesive powders tend to entrain air, creating voids for the blade to move particles into, and thereby reducing the energy associated with its movement.

NAE is determined by carrying out a BFE measurement with air flowing through the sample at a defined rate, and directly quantifies the response of the powder to air. With Cellets 350, NAE declines gradually with increasing air velocity, but in contrast, the finer Cellets samples exhibit a rapid reduction in NAE at relatively low air velocities and then exhibit a plateau at a value that indicates fluidization. The profile for the Avicel PH102 is similar. These results suggest that the coarser Cellets samples do not fluidize as readily as the finer ones, a result that reflects the greater thrust needed to fluidize larger, heavier particles.

When considering these data relative to the environment in the Wurster coater, it is reasonable to suggest that BFE data will be most informative of flow behavior in the constrained downflow zone, while NAE values are likely to inform behavior in the cylinder and conveying sections. Cores with a particle size of 350 µm typically process well in the coater. These data enable a robust assessment of how cores of different size differ in terms of flow behavior. Coating trials would confirm the results of any predictions. It is clear that flow-energy measurements are more reproducible and differentiating than data from traditional and alternative techniques. Trends are observed that are rationalized by particle size and intuitively linked to flow regimes in different areas of the coater.

Case study 2

This example describes enhancing powder characterization to achieve better product performance for cosmetic pigments. In the cosmetics industry, innovative products command a premium price in a highly competitive marketplace, though assessment of performance is often relatively subjective. Intercos Group (Intercos S.p.A, Agrate Brianza, Italy), one of the world's biggest suppliers to the cosmetics industry, has recently embarked on studies to improve formulation by adding powder characterization to its routine analysis schedule. The aim is to identify a powder-testing method that can be used to assess the flowability or "smoothness" of highly-cohesive pearlescent pigments and differentiate them with respect to the texture, applicability and coverage of formulated compacts. These vital characteristics cannot be predicted from current analyses, such as particle sizing (granulometry) and oil absorption. Furthermore, the high cohesivity of the pigments renders traditional powder testing methods, such as angle-of-repose, impractical. The work described here explains how alternative testers were assessed to identify a new solution.

In a first experiment, three pigments — bronze, white and gold — suitable for inclusion in an eyeshadow compact were tested with an avalanche tester (Revolution Powder Analyzer, Mercury Scientific Inc., Newton, Conn.). Figure 4 shows sensory data produced via a manual scoring technique for products formulated with these pigments. Formulated samples were simple blends of filler, binder and pigment, with only the pearlescent pigment changed in each case. All ingredients and overall composition otherwise were kept constant. The three formulations are comparable in terms of hardness (blue bars), a measure of texture/consistency to touch, but are scored

differently with respect to writing (red bars), which relates to pay-off, the coverage or brightness of a color on the skin. Table 2 shows the avalanche test data.

SL (solid-liquid) ratio relates avalanching behavior to the extent to which the powder exhibits solid- or liquid-like behavior. These data identify the white pigment as being more liquid-like (SL ratio closer to 0) than the other two powders (higher SL ratios; closer to 1). Avalanche energy data confirms the greater fluidity of the white and suggests a trend across the three powders. However, the error bars associated with these data (and to a lesser extent, with break energy, which exhibits the same trend) are extremely wide, compromising the statistical significance of the data.

The Hurst Index quantifies the extent to which avalanching behavior is random, as opposed to exhibiting temporal trends. This index also differentiates the powders, but the trend does not correlate with observed differences in writing performance. Rest angle, the angle the powder assumes at the end of an avalanching event identifies the gold pigment as the most cohesive of the three materials, but provides minimal differentiation between the other two samples. Finally, surface fractal, which represents the fractal dimension of the powder surface measured immediately post-avalanche, suggests that the white powder may be associated with a smoother, more uniform surface (a lower surface fractal that is closer to one).

In combination, and on balance, these data identify white as the most smoothly flowing pigment, followed by bronze and then gold. However, this ranking does not reflect the trend in writing performance, and its value is significantly undermined by the high variability associated with some parameters. It was therefore concluded that the avalanche tester could not provide useful insight for this application.

In a second experiment, tests were carried out with two pearlescent pigments — orange and bronze (as analyzed in the earlier experiment) selected on the basis of similar granulometry and oil absorption. These were subject to dynamic, shear and bulk property measurement to determine the ability of the instrument to differentiate the pigments in a relevant way. Sensory analysis identifies that the orange pigment formulates with mica into a harder compact, with lower coverage than the equivalent bronze compact.

Table 3 summarizes the differences detected in dynamic, shear and bulk properties of the two pigments. These data provide clear differentiation, consistently indicating greater cohesivity between particles of the orange pigment, and hence poorer flowability.

More specifically, both SE and BFE are substantially higher for the orange pigment relative to the bronze, indicating that it is likely to flow less easily in a wide range of processing environments. With both powders repeat BFE testing generates similar results showing them to be physically stable, though the stability index (SI) (the ratio of BFE measured in test 7 relative to the value measured in test 1) is slightly higher for the orange pigment, suggesting it may be more prone to agglomeration.

Conditioned bulk density (CBD) data, generated as a byproduct of flow-energy measurements, highlights less efficient packing in the orange powder, providing additional evidence of greater cohesion. Powders in which the cohesive forces between particles are relatively high have a greater tendency to retain air in structured pockets within the bed, resulting in lower CBD relative to a less cohesive powder in which particles pack more efficiently. More efficient packing also rationalizes the lower permeability of the bronze powder, since close packing reduces the size and number of channels through the powder bed, increasing the pressure drop associated with the transit of air.

Stronger inter-particle forces of cohesion also reduce the ability to

separate particles to minimize interparticle interactions and improve flowability. This effect is evident in the aeration ratio (AR; the ratio of BFE to AE), which is much lower for the orange pigment than for the bronze. The less cohesive bronze is more sensitive to the introduction of air. Air entrainment in the more cohesive orange powder makes it more compressible, as well as reducing CBD, and the flow function (FF) measured by shear-cell testing classifies the orange pigment as "fairly free-flowing" relative to the "free" or "excellent" flowing designation associated with the higher FF of the bronze.

The combination of dynamic, shear and bulk-powder properties consistently differentiate pigments that are equivalent on the basis of other routine analyses, but perform differently when formulated. Measuring these properties provides the information required to implement a more scientific approach to product formulation and reliably and efficiently develop products with the required properties.

The way ahead

The case studies included here illustrate the increasingly common practice of refining powder testing practices by measuring a range of parameters to identify those that offer unique insight or correlation. Advances in data processing ease the effort of handling the data generated by modern powder testers and reinforce that it is more sophisticated techniques that are most valuable, particularly for new or demanding applications. As these studies show, although most relevant parameters can be specific to the application, the ability to apply different testing protocols, for example, to measure dynamic, shear and bulk properties, is a fruitful starting point for powder processors looking to establish a powder testing strategy that is both effective and efficient. ■

Edited by Scott Jenkins

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Gas Trapping Can Unsettle Distillation Columns

Operational troubleshooting guidance is provided for several scenarios involving trapped non-condensable gases in distillation towers

Henry Z. Kister
Fluor Corp.

IN BRIEF

Non-condensable gases are often present in distillation towers, either expectedly or unexpectedly. When they do appear, or when the quantity of non-condensable gases varies from the design or expectation, they can adversely affect condensation, cause instability or lead to excessive venting and product loss. Some of the causes of gas trapping issues are well known, while others remain obscure. This article briefly describes the better-known issues, while focusing on those that are more obscure, presenting experiences in which non-condensable gas trapping led to operating problems. Gas trapping issues in distillation towers can be classified into three groups:

- Gas trapping due to tower or auxiliary equipment hardware
- Gas trapping due to liquid head
- Unexpected quantity of gas (high or low) entering the tower

Each of these points are addressed and discussed in this article, with some guidelines for preventing and overcoming gas-trapping issues.

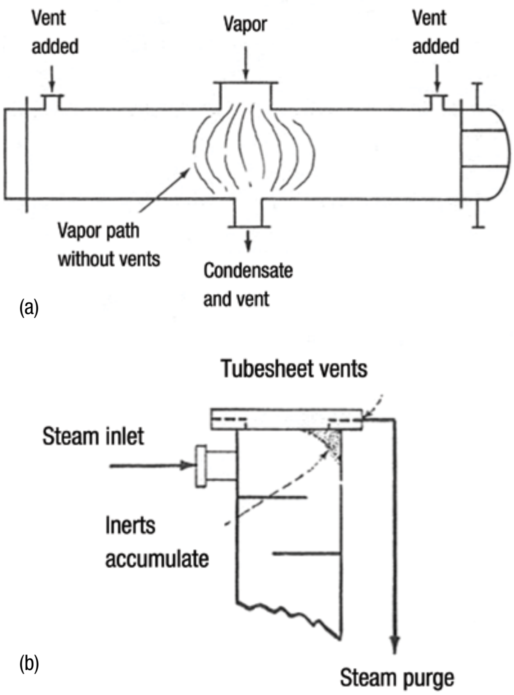

FIGURE 1. Illustrated here are the locations of vents on condensing exchangers to remove non-condensable gas. As shown in 1a, adding properly located vents in a horizontal condenser can eliminate inert blanketing [*9*]. In 1b, a tubesheet vent is installed in a steam-heated vertical reboiler [*8*]. (Reprinted courtesy of *Chem. Eng.*)

Equipment-related gas trapping

Gas-trapping issues associated with the tower equipment itself, or its auxiliary equipment hardware, are some of the more common and better-known issues, and are therefore only discussed briefly here.

Condensers and reboilers using a condensing heating medium. Gas trapping in condensers and reboilers is well known, and is discussed at length by many references [*1–5*]. A famous statement by Smith [*3*] is that to troubleshoot a condenser, one needs to ask three questions: "Is it clean? Is it vented? Is it drained?" Prof. Bell, the legendary heat-transfer expert, estimated that inadequate venting of non-condensable gases accounts for half of condenser malfunctions [*2*]. Twenty years later, a malfunction survey [*6*] reinforced his statement with a slightly smaller fraction of 41%.

Accumulation of even a small fraction of non-condensable gas can impair condensation. The non-condensable gas increases the vapor-phase resistance to heat transfer. In addition, the gas depresses the condensate partial pressure, lowering the condensing temperature and therefore the log mean temperature difference. The diffusional re-

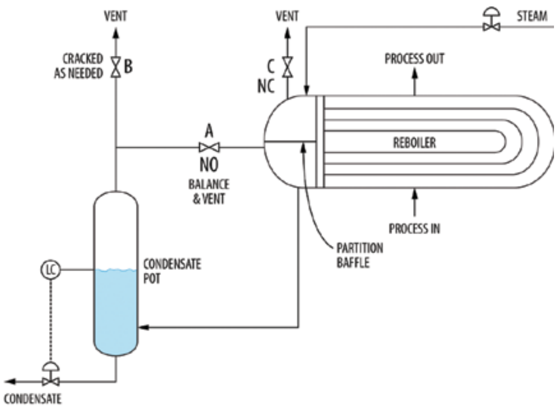

FIGURE 2. This configuration shows adequate venting in a horizontal thermosiphon reboiler. The balance line and vent are drawn from below the partition baffle

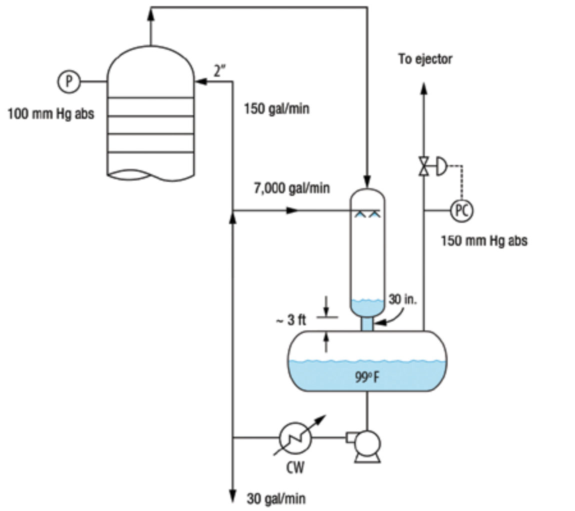

FIGURE 3. This tower experienced pressure fluctuations and intermittent flooding near the top due to gas trapping by the liquid leg in the drain pipe from the direct-contact condenser

sistance to mass transfer is also important. For film condensation, the heavier components must diffuse to the interface. Heavy components diffuse slowly, and a high concentration of non-condensable gas retards their diffusion. As heavy components condense out, the vapor near the interface becomes leaner in heavy components and richer in non-condensable gas, which further retards diffusion. These mechanisms are responsible for the phenomenon termed "inert blanketing," which drastically reduces condensation rates in condensers. When the non-condensable gases are acidic or corrosive, like CO_2, their accumulation is known to have caused severe corrosion [*7*, *8*, *11*].

Several guidelines have been proposed for venting non-condensable gases from condensers and from the condensing side of reboilers [*1–4*]:

1. There should be a clear flow path to positively guide non-condensable gases from the exchanger inlet to the vent. If the flow path is governed by baffles, baffle design should ensure adequate sweeping of the gas.
2. The vents should be located at the end of the flow path. Gilmour [*9*] describes a case history of inert blanketing of the condenser shown in Figure 1 before the vents were added. A similar problem was also reported by others [*3*].
3. Figure 2 shows adequate venting of a horizontal thermosiphon reboiler. The balance line goes from below the partition baffle to the top of the condensate pot to minimize condensate backup into the reboiler, as advocated by Risko [*5*] and Lieberman [*7*]. Venting is accomplished by cracking valve B open. Opening valve C vents inlet steam, but not the non-condensable gas, so it is useful only for clearing the air out during startup. Similar principles apply to some in-tube condensers, but there the vent valve B is usually mounted on the reflux drum.
4. The flow path should preferably be tapered to maintain high velocities and to avoid gas collection in dead pockets.
5. The effect of different cooling conditions on the regions where non-condensable gases are trapped should be considered.
6. All vapors to be condensed should be considered to contain non-condensable gases. Note that 100 parts per million (ppm) of non-condensable gas in a vapor can fill a reboiler up with non-condensable gas in less than 10 h [*2*].
7. In vertical reboilers, it is a good practice to provide tubesheet vents [*1*, *8–10*], as shown in Figure 1b, opposite the top vapor-inlet nozzle. This is essential if the non-condensable gas is acidic or corrosive, such as CO_2.
8. Carefully review the vent line piping to ensure it is not choked by a liquid head.
9. Carefully review the condenser design for the possibility of Rayleigh condensation. This occurs when liquid condensed close to the condenser entry, rich in heavy components, is removed as soon as it is formed, and is no longer mixed with the remaining condensing mixture. This mode concentrates the non-condensable gas in the condensing mixture, lowering the vapor dewpoint, and preventing its removal by absorption in the condensate. Case 1.13 in Ref. 15, contributed by Hollowell, describes a case where "an entire refinery capacity was sometimes limited by the gas rate, that was calculated to be zero" (because Rayleigh condensation occurred but was not accounted for in the design calculations).
10. Adequate venting is most important during startup, when air or nitrogen is likely to be present.

Trapping of gas in liquid collection sumps. Liquids in towers are collected in bottom sumps, chimney trays, downcomer trapouts, redistributors and collectors. These liquids inherently contain gas or vapor bubbles. As a rule of thumb, a degassing time of 0.5 to 1 min is needed to degas this liquid [*1*]. In addition, gas or vapor can be entrained into these liquids by frothing (known as "waterfall pool effect"), gas jets directed into the liquid, flashing (especially when hot and cold liquids are mixed) and vortexing. This subject is discussed at length in Ref. 1.

Gas trapping by liquid head

The mechanisms of gas trapping by liquid head are not as well-documented or widely discussed, and therefore are presented in more detail here.

Trapping of gas by liquid level at drum, condenser, or bottom sump baffles. This is the most common mechanism in this class. An excellent example of this issue is described in detail in Case Study 24.3,

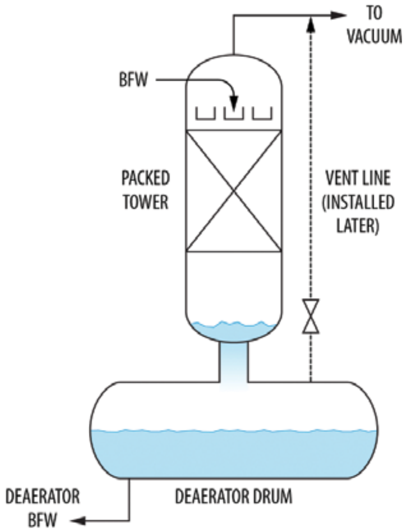

FIGURE 4. This diagram shows a deaerator that was experiencing pressuring up and cycling

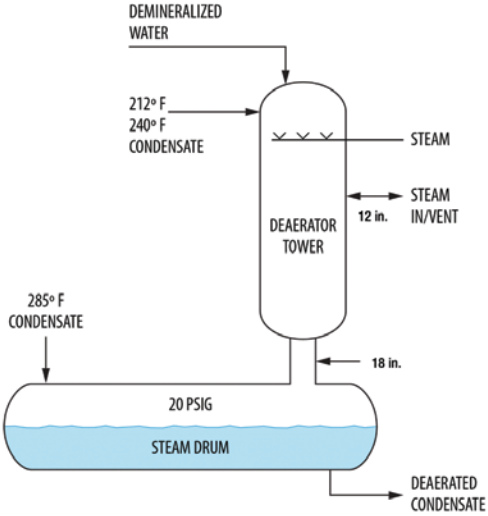

FIGURE 5. This diagram shows an aerator that was experiencing violent shaking

co-authored by Olsson and the author in Ref. 15. Overheads from a chemical tower (Figure 3) were condensed in a spray condenser by direct contact with cooled circulating reflux. The condenser drained freely to the reflux drum. Non-condensable gases from the reflux drum went to the vacuum system. The tower experienced pressure fluctuations and intermittent flooding near the top.

A key observation was that the reflux accumulator was at 150 mm Hg, while the tower top was at 100 mm Hg. This can only be explained by a liquid leg in the condenser and in the short pipe between the condenser and reflux drum pulling the other 50 mm Hg of the vacuum in the tower. Operating records confirmed that the 50 mm Hg pressure difference was established as soon as liquid circulation was established, meaning it occurred before vapor was flowing through the tower. This pressure difference was therefore produced by the liquid. The short 30-in. dia. pipe was 3 ft long. At the normal circulation rate, there was an estimated pressure drop of 1 ft of liquid in the pipe (mostly entrance and exit). This leaves 2 ft of net suction, which roughly coincides with the pressure difference (50 mm Hg) between the accumulator and the tower. Calculations using the correlation in Ref. 1 showed that the 30-in. pipe was capable of handling up to 5,400 gal/min of self-venting flow. The actual liquid flowrate leaving the condenser was much higher, at 7,200 gal/min.

This means that some liquid backed up in the condenser, and that the 30-in. pipe was running liquid-full.

The liquid leg prevented non-condensable gases from freely leaving the condenser bottom. The gases were trapped in the condenser, raising its pressure. With the pressure in the accumulator fixed by the pressure control, the pressure in the tower and condenser would slowly rise, until there was enough pressure difference to push the liquid leg into the reflux drum and release the gas. Once vented, the tower pressure fell. When more non-condensable gas entered the system, fluctuations intensified.

The fall of the tower top pressure during the cycle could have induced intermittent flooding. Once flooded, hot liquid was entrained by the tower overhead vapor. This heavy-rich liquid absorbed some of the lighter components, dropping pressure in the condenser, and aggravating the flooding.

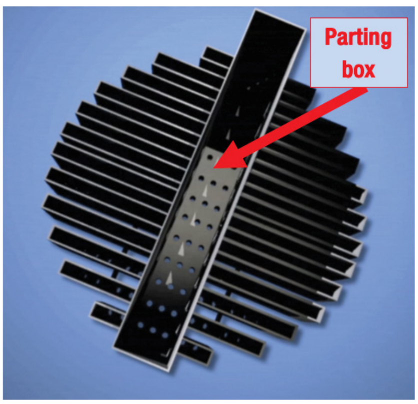

FIGURE 6. A parting box serves to meter liquid to the troughs of a packing distributor. In this distributor, there are holes in the bottom of the troughs, visible in the three troughs in the bottom left of the photograph (Reprinted courtesy of Fractionation Research Inc.)

To solve the problem, the pressure controller was relocated from the top of the reflux drum to the tower overhead upstream of the condenser. This kept a steady pressure in the tower and completely eliminated the pressure fluctuations.

In an analogous case, a boiler feedwater (BFW) deaerator drum (Figure 4) would pressure up. Once it pressured up, air removal from the condensate deteriorated, raising the air concentration in the condensate from 10 to 700 ppm. There was also an instability issue — the deaerator drum would pressure up and then the pressure would suddenly be released.

The cause was that the drain line from the packed tower above was undersized for self-venting flow. This backed up liquid in the packed tower. Eventually, either a vapor slug broke through or the liquid siphoned out and the process repeated. The

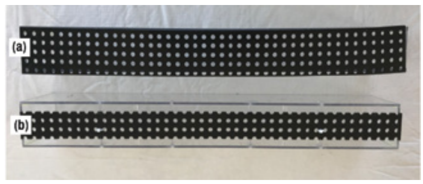

FIGURE 7. Impingement plate design impacts venting [*12*]. A perforated impingement plate (PIP), shown in 7a is the same width as the parting box, extending from wall to wall. A vented impingement plate (VIP), shown in 7b, has gaps between the main walls of the parting box insert and the plate (Reprinted courtesy of AIChE)

FIGURE 8. Tests were conducted with a 20% open area PIP, 4 in. above the parting box floor [*12*]. The liquid level at the bottom of the box was only about 1 in., with an air gap occupying the other 3 in. between the PIP and the floor of the box (Reprinted courtesy of AIChE)

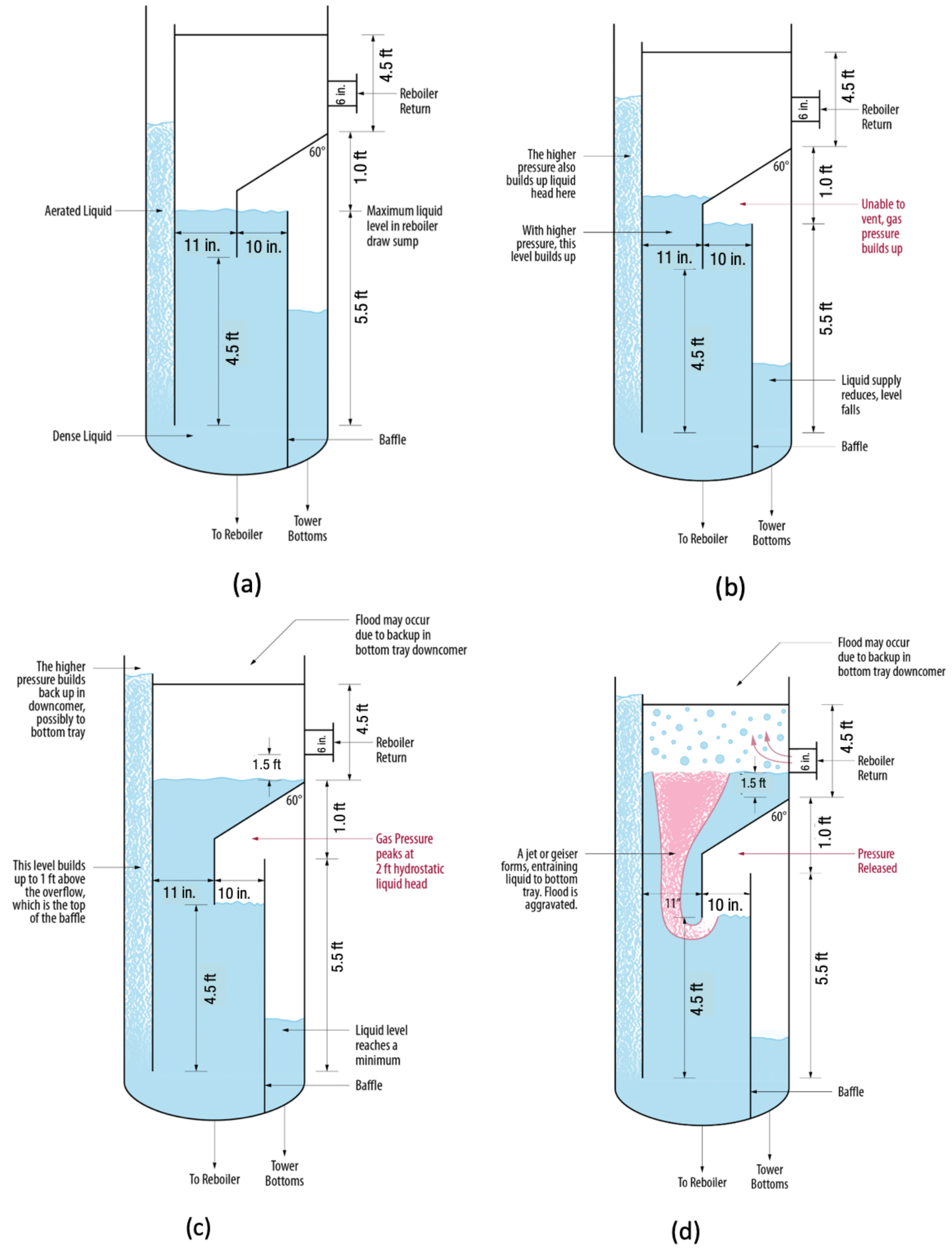

FIGURE 9. This debutanizer bottom sump cycle, detailed in Ref. 13, shows four stages: (a) initial steady state; (b) pressure buildup; (c) pressure peaks; and (d) vapor breakthrough and pressure release (Reprinted courtesy of PTQ)

problem was eliminated by installing a vent line (shown dashed) from the drum to the packed tower overhead.

Another deaerator (Figure 5) received steam condensate from three sources: 212°F, 240°F and 285°F at variable flowrates, as well as a demineralized water makeup at 90°F. The 12-in. line served both as a vent and a heating line.

Initially, all three condensate streams entered the top of the tower. Later, the 285°F condensate was routed into the steam drum as shown in Figure 5 to reduce steam venting. Upon restart, at high condensate rates the deaerator shook violently. There was so much flash steam in the drum that the vapor velocity up the 18-in. line was high enough to exceed the system limit [*16*]. To stop the shaking, the drum pressure was raised from 12 psig to 20 psig, which lowered the vapor velocity below the system limit. The liquid downflow rate of about 300 gal/min was not high for an 18-in. line, so the problem was vapor-driven.

Trapping of gas generated by liquid jets. Liquid feeds often enter the tower as liquid jets. When liquid jets impact on a liquid surface, they entrain vapor into the liquid. When the entrained vapor cannot freely vent out, it may cause liquid backup, as in the situation described below.

A parting box is a rectangular box typically mounted right above packed-tower distributor troughs (Figure 6). A feed sparger pipe elevated just above the box and oriented parallel to it supplies liquid to the box. The pipe may contain holes in its underside or dip tubes that transport the liquid to near the bottom of the box [*12*]. The liquid may be overhead reflux, collected internal liquid mixed with liquid feed, or pump-around return liquid. Holes in the floor of the parting box, located above each of the troughs, meter the liquid to each trough (Figure 6), targeting a uniform liquid head in all the troughs.

When feeding the box from a sparger containing holes in the underside (no dip tubes), the liquid jets issuing from the holes impact the liquid surface in the box, generating intense uneven frothing in the box, which in turn leads to maldistribution of liquid to the troughs. A perforated impingement plate (PIP; shown in Figure 7a), stretching wall-to-wall in the box, mounted 2 to 4 in. above the floor, with perforation area typically 10–20% of the box cross-sectional area, is often used to even the froth. The area of the holes of the PIP significantly exceeds the hole area at

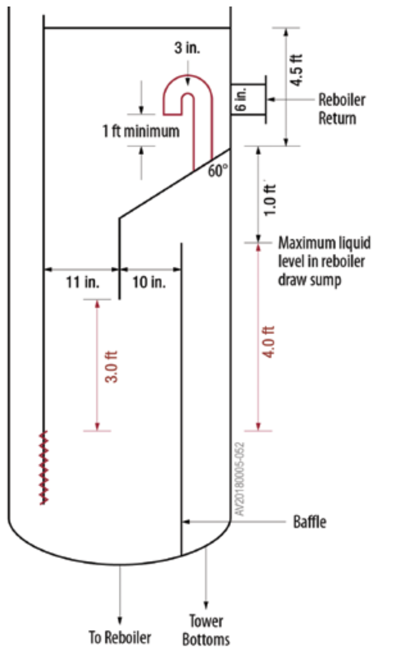

FIGURE 10. Adding a goose-neck vent allowed gas to escape from the bottoms draw sump and eliminated swings [*13*] (Reprinted courtesy of PTQ)

the bottom of the parting box, so the PIP does not retard the flow. Rather, it breaks the momentum, evens the froth and improves the distribution of liquid exiting the box [*12*].

Recent tests with water using a scaled-down model of an actual parting box showed a venting issue when using a PIP [*12*]. Water jets exiting the sparger feed pipe entrained air upon impact with the PIP and the water above it (Figure 8). This air passed downward through the PIP and was trapped beneath it by the prevailing water head above the PIP. This air gap generated excessive froth heights above the PIP, leading to premature overflows from the box. Overflowing liquid is maldistributed and often picked up by the vapor, causing entrainment and premature flooding in packed towers [*6*].

Adequate venting of the PIP is achieved in some commercial designs by using a narrower impingement plate that leaves gaps on the sides to permit gas venting. Such vented impingement plates (VIPs; Figure 7b) were tested in the same test rig. The tests showed that using the VIPs with 40–50% open area completely eliminated the air gap, lowered the froth heights and eliminated the box overflow, while still providing an excellent liquid split to the parting box perforations at full rates and down to 50% turndown. The takeaway is that when perforated impingement plates are used in parting boxes, they should be well-vented. We have seen a case where overflow from a parting box containing a PIP caused a separation deterioration at high rates.

Trapping of gas by bottom sump baffles. Inadequate venting of a bottom sump baffle can cause liquid to back up above the baffle. This backup can initiate cycling or premature flooding. In one case described in Ref. 13, the base level swung by as much as 30% of its range every 10 min, resulting in bottoms flow swings between zero and 3,000 lb/h. The tower differential pressure (dP) and some temperatures also fluctuated.

Figure 9a shows the baffle arrangement at the bottom of a debutanizer tower [*13*]. The downcomer from the bottom tray is submerged deep within the reboiler draw sump. Liquid from the reboiler return flows to the top of the sump, under an upper sloped baffle, and then overflows a vertical baffle to reach the bottom sump. Note that the downcomer contains frothy liquid that has a lower specific gravity than the reboiler sump liquid, causing it to rise to a greater height.

Figure 9b shows the key issue. The vapor space above the bottom compartment is not vented, so vapor getting in cannot get out and will back-pressure the liquid in the reboiler draw compartment. Less liquid will overflow the vertical baffle, and the bottom level will drop. The higher pressure in the vapor space above the bottom compartment will push liquid up in the reboiler draw compartment, and its level would rise. This will also raise the backup of frothy liquid in the bottom downcomer towards the bottom tray.

This process will continue until the liquid head above the vertical baffle reaches about 2 ft, at which time the vapor space above the bottom compartment would reach the bottom of the sloped baffle (Figure 9c). The tower bottom level will reach a minimum, while the frothy liquid height in the bottom downcomer will peak, possibly flooding the bottom tray.

A vapor path now forms and the trapped vapor geysers out through the liquid (Figure 9d). Once the puff is gone, the reboiler draw compartment returns to its initial state in Figure 9a, and the process would repeat. This mechanism explained the observed fluctuations in the debutanizer.

To overcome the venting problem, the solution was to vent the bottom draw compartment using a goose-neck vent (Figure 10), and to shorten the downcomer from the bottom tray, reducing its submergence. This completely eliminated the swings.

Trapping of gas in flooded reflux drums. In many total condensing systems, the reflux drums operate liquid-full and the tower pressure is controlled by manipulating the distillate rate (PC 1 in Figure 11). With the liquid-full drum, closing the valve raises the liquid level in the condenser, covering some of its heat transfer area, which in turn reduces condensation rates and raises tower pressure. Conversely, opening the distillate valve PC 1 lowers the liquid level in the condenser, exposing more tube surface for condensation, which lowers the tower pressure. Sometimes, especially in gravity systems that have no reflux pump, the reflux drum itself is omitted. Due to the absence of vapor space, the flooded drum is smaller than a drum with a vapor space, the piping is simpler, and together with the elimination of the level control offers handsome capital cost savings.

Besides the condenser venting issue described earlier, the flooded drum has an additional potential venting issue. Desorption of non-condensable gases in the drum may unflood the drum and interrupt the control action. These non-condensable gases cannot return to the condenser due to the liquid leg in the line from the condenser. They need to be vented from near the top of a liquid-full drum, so the vent is likely to contain entrained liquid. The vent system and downstream need to safely handle the entrained liquid and its flash. Failure to vent these gases would render the pressure control erratic, swinging the reflux and distillate systems. If non-condensable accu-

mulation is infrequent, manual venting from the top of the drum is often sufficient. If non-condensable gases accumulate frequently, or the column is run unattended, automatic venting is required.

Figure 11 illustrates an automatic vent system that has worked well [*1*, *14*, *15*]. A second pressure controller (PC 2), a level controller, and a control valve in the vent line are added. The set point of PC 2 is lower than that of the normal pressure controller (PC 1). When the drum is full, the level controller keeps PC 2 tripped off, and the vent valve is closed. Drum unflooding (due to non-condensable gas trapping) is sensed by a drop in drum level. The lower level activates PC 2. Since the setpoint of PC 2 is lower than PC 1, it opens the vent valve. As the pressure falls, PC 1 closes, helping to build up the drum liquid level. As soon as the drum refills, the level controller trips PC 2, and the vent valve closes.

Excessive gas in the tower

Issues with an excessive quantity of gas entering the tower are common, potentially troublesome, and often are unacknowledged. This is considered in detail here. In vacuum towers, there may also be issues with deficient quantities of gas entering the tower. These too are addressed.

The economic impact of non-condensable gas venting. Other than operating issues and instability in the tower, the vented non-condensable gas usually drags some product with it, which is lost. These product losses can be quite expensive, as is illustrated in the following example.

Consider a tower whose overhead product is hexane, with the reflux drum at 30 psia and 80°F. There is also some nitrogen in the drum, whether coming from the process or from a control system that adds non-condensable gas to maintain the drum (and tower) pressure. The drum pressure (P_{drum}, psia) is the sum of the partial pressures of the liquid and that of the gas, given by Equation (1):

$$P_{drum} = VP_{liquid} + P_{gas} \quad (1)$$

Assuming ideality and equilibrium, the partial pressure of the hexane liquid equals its vapor pressure, VP_{liquid}, in psia. P_{gas} is the partial pressure of the gas in psia. At 80ºF, the vapor pressure of hexane liquid is 3.1 psia. This means that the gas partial pressure is 30 psia – 3.1 psia = 26.9 psia. On a molar basis, 10% (equal to 3.1 psia divided by 30 psia) of the vent gas at 80°F will be hexane. On a weight basis, the hexane fraction of the vent gas is higher at 26%, due to the lower molecular weight of the nitrogen. So, every ton of vent gas contains 0.26 tons of hexane. This vented product is likely to be lost, and may increase flaring or emissions. The non-condensable gas, even nitrogen, can be absorbed into the product, and can later increase pressure in downstream equipment, resulting in more product loss and flaring downstream, as discussed below.

To minimize the losses of product in the vent, the vent gas is sometimes chilled, often in a knock-back condenser, and the condensate recovered. Even cooling by as little as 20°F (to 60°F), which can be achieved with cold water, would reduce the liquid hexane vapor pressure to 1.8 psia. It also would reduce the hexane content of the vent gas from 26 wt.% to 16 wt.%, almost halving the product loss in the gas.

Gas absorption by feed or reflux drum liquid. This mechanism is one of the most common, yet unappreciated, sources of wasteful venting. It is often inconceivable to think that a gas like nitrogen or fuel gas can be absorbed in significant quantities by process liquids. Given enough contact surface, the relatively small quantity absorbed can become significant, turn into a major economic loss, and generate environmental issues and tower instability, as described below.

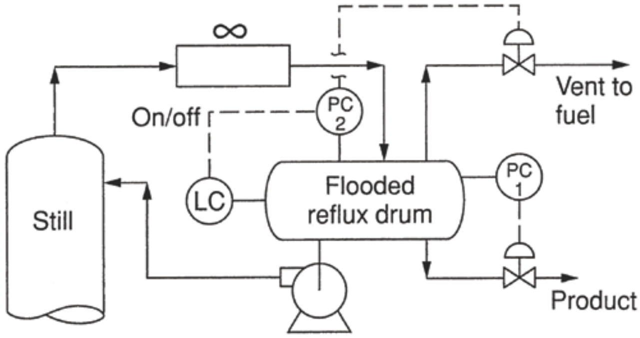

FIGURE 11. This configuration shows a flooded-drum automatic vent system that worked well [*14*] (Reprinted courtesy of AIChE)

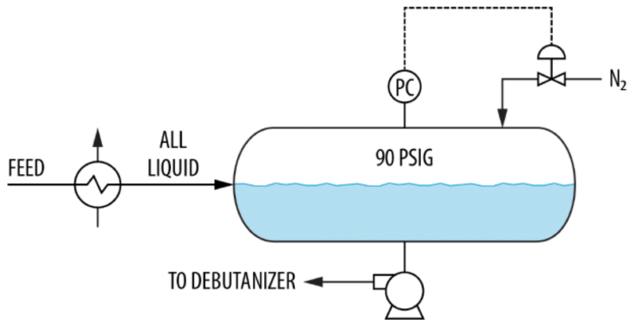

FIGURE 12. Here, nitrogen is absorbed by the liquid in a newly added debutanizer feed drum

Nitrogen was used to maintain pressure in a newly added debutanizer feed drum (Figure 12). Following restart, it was observed that much of the nitrogen ended up in the downstream plant. The plant needed to do considerable venting from the downstream debutanizer, deisobutanizer and depropanizer. The nitrogen got into all of these towers. The plant operators also noticed that the nitrogen control valve was opening almost fully, suggesting that a lot of nitrogen was coming in. This nitrogen had to get out, and the only open route is with the drum outlet liquid.

The high absorption rate was due to the feed entry near the liquid surface. This exposed extensive contact area between the feed liquid and the nitrogen in the drum vapor space. The way to avoid this is to pipe the feed liquid to discharge near the bottom of the drum, so the entering liquid has no contact with the vapor space. The only contact

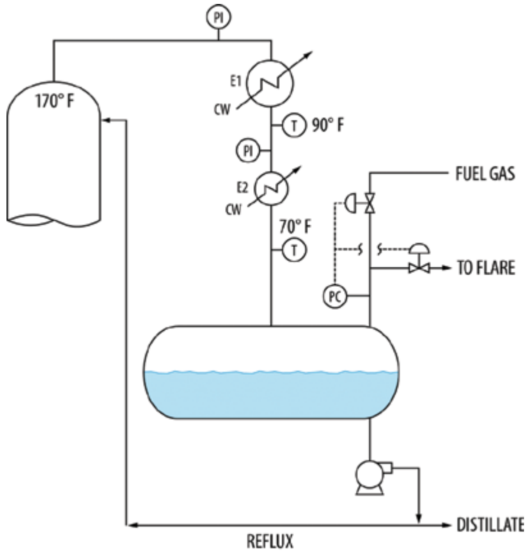

FIGURE 13. Fuel gas absorbed by the liquid in a reflux drum causes pressure fluctuations in towers and condensers

area between the nitrogen and the liquid is then the stagnant surface, that will reach saturation and, as long as it remains undisturbed, will not absorb additional nitrogen.

A possible "band-aid" solution would have been to raise the liquid level, but this was undesirable because the feed frequently fluctuated, so the level was controlled at 50%. Other temporary solutions would be to keep the feed warmer or reduce the drum pressure, which the plant did until a permanent solution could be implemented.

In another tower, a split-range pressure controller on the reflux drum would either bring fuel gas in or vent gas to the flare (Figure 13). The valve adding fuel gas was always widely open and the valve to the flare closed, which was desirable to minimize flaring. The wide opening means that a significant quantity of fuel gas was absorbed by the drum liquid. The pressure control kept the drum pressure steady, but the tower pressure would swing by as much as 7 psi.

The tower overhead at 170ºF was totally condensed in exchanger E1, with an outlet temperature of 90ºF, then subcooled by exchanger E2 to 70ºF. The pressure drop across the condensers varied between 3 and 15 psi depending on the rates. As the rates increased, the pressure drop across each exchanger would rise, reaching as high as 7 psi across each exchanger. The high exchanger pressure drops, especially in subcooler E2, could only be explained by the presence of gas.

The subcooled liquid entry (by splashing onto the drum surface) would generate a large surface to absorb the gas. This gas exited in the drum liquid. Some ended in the distillate product, the rest was refluxed. In the tower, the gases absorbed in the reflux stream were desorbed, and gas blanketed the condenser and subcooler, causing the high and fluctuating dP that destabilized the tower pressure control.

A solution would be to extend the condensate pipe to near the bottom of the reflux drum. This would shield the condensate from the fuel gas and mitigate the absorption of fuel gas. The only absorption would take place right at the drum surface. As long as the surface remained undisturbed, it would quickly become saturated and there will be little additional fuel gas absorption.

Deficient or variable gas quantity

Tower design is usually based on a range of expected quantities of noncondensable gases entering the tower. When the actual quantity deviates from the design, the control system may not keep up with it, causing swings or other major operation issues. Theunick's statement in Ref. 18 — "Effectively managing the vapor inventory is the key to controlling the pressure" — summarizes this issue.

According to Equation (1), when the product vapor pressure, VP_{liquid} is low, and at the same time there is not enough non-condensable gas to keep the pressure P_{gas} high, the drum pressure, P_{drum}, will fall, at times below the desired setpoint on the pressure controller. Lowering the controller setpoint reduces tower pressure, raising vapor velocities in the tower, which in turn may induce premature flooding or entrainment, possibly limiting tower capacity. Attempting to keep the controller at the higher (desired) setpoint may induce cycles of accumulating and discharging the little non-condensable gas that is present. The swings can be severe — in one case described in Ref. 18, tower pressure cycled by 20% every 6 min, inducing temperature swings as high as 90ºF, temperature inversions and off-specification product. The problem was generated by the absence of a low-boiler, which acted as a non-condensable gas. The problem was solved by adding nitrogen downstream of the condenser to increase P_{gas}.

Another superb illustration of this issue is in the vacuum tower described by Van der Merwe in Ref. 17. Figure 14 is a simplified diagram of the tower based on Ref. 17. The tower had an internal large dimple plate condenser (E-1) using a treated condensate stream referred to as warm tempered water (WTW) entering at 130ºF, and a smaller internal dimple-plate inerts cooler (E-2) using colder WTW (95ºF), with 1/20th the duty of E-1. The main pressure control on the tower was by manipulating the WTW rate from E-1. In case of excess pressure, the inerts flow to the vacuum system would be increased by the other pressure controller. The operator had the ability to manipulate the flow of inerts to the vacuum via the HC.

As it turned out, the actual air ingress into the system was 1/100th of the design. For vacuum towers, the design leakage rate is usually

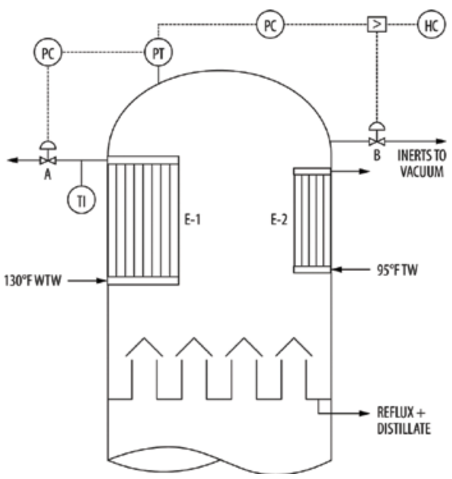

FIGURE 14. Based on Ref. 17, a vacuum tower is shown that experienced severe pressure-control problems

based on the number and sizes of flanges in the system, and it appears that the construction crew did too good a job of tightening all the flanges. The absence of inerts enhanced condensation, causing the pressure to fall. To keep up the pressure, the plant cut back the WTW flowrate, but this raised the WTW outlet temperature, which reached the maximum allowable to prevent WTW boiling. This was not sufficient to bring up the tower pressure, and it ended about 6 psi below design, which limited tower hydraulic capacity.

To compensate for the lack of air ingress, a metered nitrogen purge was added to the tower. This did not work as intended, and the tower pressure experienced oscillations of ±1.5 psi, causing temperature and level oscillations, probably because of the delicate balance required between the control valve characteristics and the nitrogen addition rate.

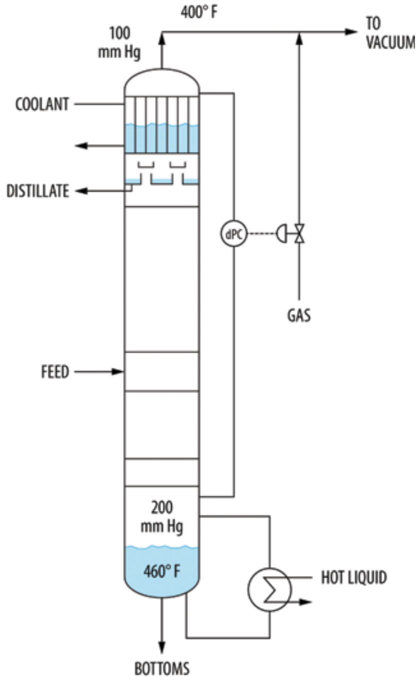

FIGURE 15. A steam leak caused pressure-control problems in this vacuum tower system

The problem was eventually solved by changing the pressure control philosophy, and adding a WTW outlet temperature control, keeping the WTW valve as open as possible, and allowing a smaller margin between the WTW outlet temperature and its boiling point. The improved control arrangement is spelled out in detail in Ref. 17.

Case 24.5 in Ref. 15 describes an analogous problem, except that the condenser used cooling water, with the condensate temperature 250ºF. At low rates, the cooling-water valve closed, inducing high outlet temperatures accompanied by severe tube corrosion and even water boiling. Fouling was not a problem because the condenser was cleaned every few weeks. In this case, adding a nitrogen purge successfully reduced condenser heat transfer, which permitted larger opening of the cooling water valve, preventing excessive temperatures.

Another example is the vacuum tower in Figure 15. This tower had a differential pressure controller (dPC) manipulating the addition of non-condensable gas

to the tower overhead. A fall of the top pressure would increase the differential pressure, and the dPC would bring in gas to keep up the pressure. This worked well for years.

At one time, a steam leak from a service line into the tower caused major swings to occur. At the tower temperatures and pressures, the steam behaved as a non-condensable gas, greatly reducing the condenser heat transfer, as observed by a dramatic fall in the coolant level in the condenser shell. When the quantity of non-condensable gases (including steam) entering the tower exceeded the ability of the vacuum jets to remove them, the condenser became fully inert-blanketed. Condensation stopped, the product rate dropped and was lost, the top pressure drastically increased and the tower differential pressure dived.

Once the differential pressure fell, the dPC cut the gas flow to the tower overhead, helping the vacuum system remove the non-condensable gases from the condenser. The condenser was resuscitated, gradually bringing the tower pressure down. When the differential pressure returned to normal, the non-condensables rate entering the tower would again exceed its removal rate, and the cycle would repeat.

In systems similar to those in Figures 14 and 15, a high non-condensable gas rate can cause excessive upward vapor velocities in the knock-back condenser, with liquid carryover downstream. This was also reported in Case Study 24.5 in Ref. 15, and was solved by adding a valve limiter on the valve to the vacuum system (equivalent to valve B in Figure 14).

Closing throughts

Venting issues are far more common than people think. The author has often been called in to troubleshoot an operating problem, such as tower instability, poor separation or excessive product loss, which turned out to be a venting issue. The purpose of this article is to bring these venting issues to the troubleshooter's checklist by presenting common experiences with trapped gases and how the issues were solved. Following such guidance should contribute to fewer venting issues and more trouble-free towers. ■

Edited by Mary Page Bailey

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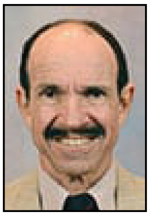
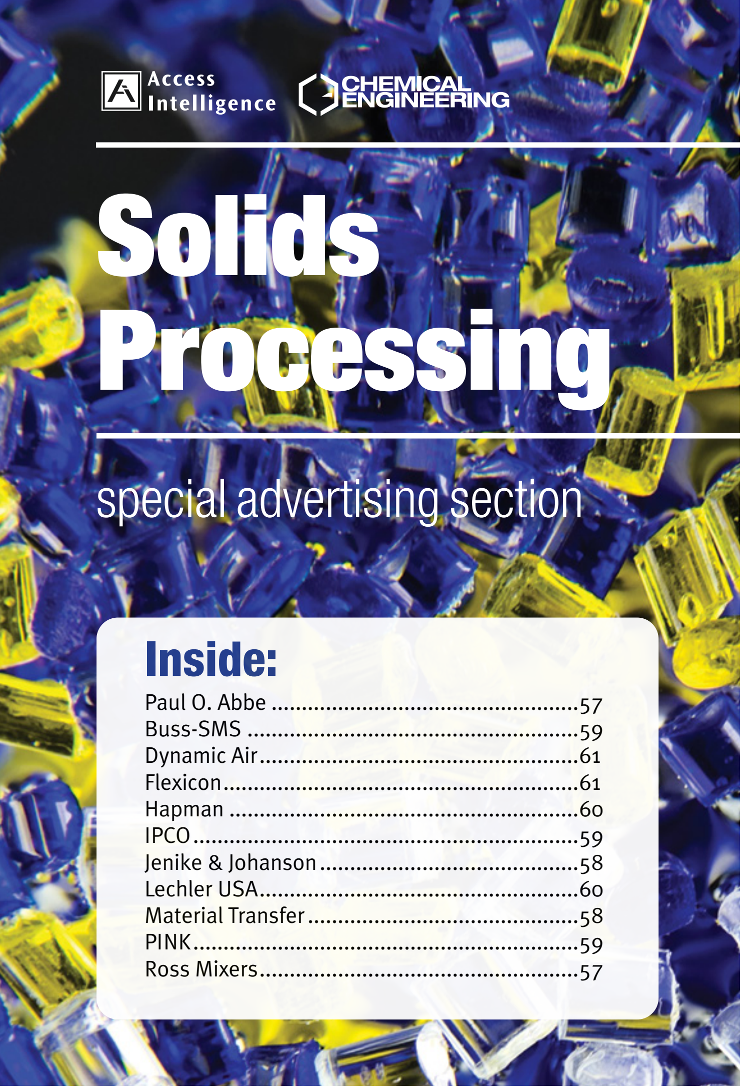


Henry Z. Kister is a senior fellow and the director of fractionation technology at Fluor Corp. (3 Polaris Way, Aliso Viejo, CA; Phone: 949-349-4679; Email: henry.kister@fluor.com). He has over 35 years experience in design, troubleshooting, revamping, field consulting, control and startup of fractionation processes and equipment. Kister is the author of three books, the distillation equipment chapter in Perry's Handbook, and over 130 articles, and has taught the IChemE-sponsored "Practical Distillation Technology" course more than 530 times in 26 countries. A recipient of several awards, Kister obtained his B.E. and M.E. degrees from the University of New South Wales in Australia. He is a Fellow of IChemE and AIChE, and serves on the FRI Technical Advisory and Design Practices Committees.



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The chemicals industry provides the building blocks for companies manufacturing paints, pigments, coatings, adhesives, resins, consumer products, and foods. 75% of all chemicals are handled in bulk solid form during manufacturing. When feeding powders to reactors or conveying wet cake from a centrifuge to a dryer, poor material flow can result in throughput limitations, non-uniform product, or dust emissions/spillage.

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Oleochemicals such as fatty alcohols, fatty acids, and PEG (polyethyleneglycol) are widely used in food and cosmetic products, sectors noted for the need for the highest standards of hygiene. As these base chemicals are usually converted into a solid form ahead of production for ease of handling and dosing, this means that upstream solidification must meet similar standards.

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For oleochemicals, typical pastille size is 4-6 mm dia. And bulk density of solid product can be as high as 500kg/m3.

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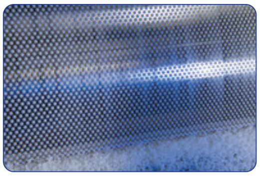

Rotoform pastillation of oleochemicals

This is particularly impressive given the difficult-to-solidify nature of certain oleochemicals. The main challenge is the heat of fusion released as the product changes state from liquid melt to solid form; typically around 200 kJ/kgK.

In the Rotoform process, this heat is transferred from the product in a highly efficient way – via the steel belt – to cooling water sprayed onto the underside of the belt. The system acts as a heat exchanger; the larger the exchange surface, the more heat can be transferred.

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Solutions, suspensions, slurries, pastes, filter cakes and moist granules are all typical feed materials to be dried. **Buss-SMS-Canzler** recommends contact drying with direct heat transfer through contact of the product with the heating surface for all these feed materials. Contact dryers can be operated under vacuum and therefore allow low temperature processing. Because of these and other advantages SMS offers several dryer types which allow the effective drying of substances like salt solutions, sewage sludge, and tar sludges from different industries.

The vertical thin film dryer consists of a vertical cylindrical body with heating jacket. A rotor inside the body is equipped with rows of pendulum blades. The wet feed is spread by the pendulum blades in a thin layer onto the wall. Because of the very effective heat transfer the feed can be processed from liquid to solid in one step.

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Lechler has more than ten full cone nozzle designs that excel in one of the above attributes. Such a level of design variety enables Lechler to select the most optimum design and nozzle size to achieve the best performance. Poorly selected nozzles can lead to millions of dollars in unrealized potential and cause thousands in damage from unplanned outages and downstream equipment failure. For example, a more efficient dual fluid nozzle requires very short residence time leading to a smaller vessel volume resulting in lower fabrication and structural costs.

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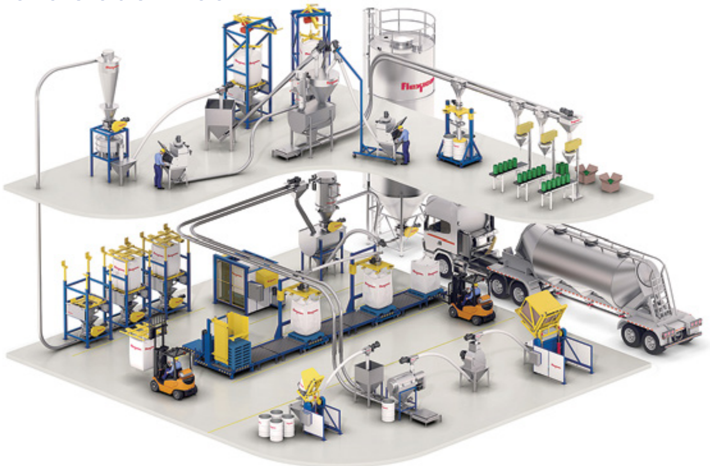

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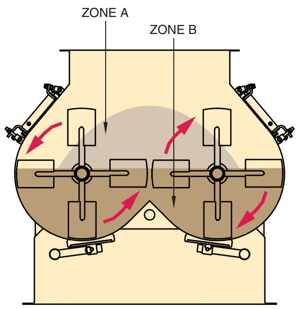
The twin-shaft Bella mixer

The Bella fluidized-zone twin-shaft paddle mixer by **Dynamic Air** achieves fast, high-capacity, low-shear, precision mixing of either dry bulk solids or liquids with solids. Regardless of particle size, shape or density, materials are mixed with a fast, efficient, and gentle action, with typical mixing times of 15–30 s. A weightless zone created by low-speed counter-rotating paddles generates low friction without shear. This makes it ideal for abrasive products and fragile products that cannot tolerate rough handling. Even flakes or spray-dried bodies remain intact.

The Bella mixer consists of twin drums which have two counter-rotating agitators with specifically angled paddles. The paddles sweep the entire bottom of both mixer drums and yet allow the mixer to be started under full load (Figure 1). The material in the mixer moves in a horizontal counter-clockwise direction at the perimeter while simultaneously moving both left and right in the center (Figure 2). The material in Zone B (Figure 1) is in its normal gravimetric state as it is being moved and dispersed. In Zone A, a weightless zone is created which effectively lifts the ingredients to an almost weightless state, allowing them to move freely and randomly, regardless of particle size and density. Thus the two zones' interaction becomes highly efficient as every particle moves rapidly to create a highly homogeneous mix, the key to the Bella mixer mixing technology for fast, precise mixing.



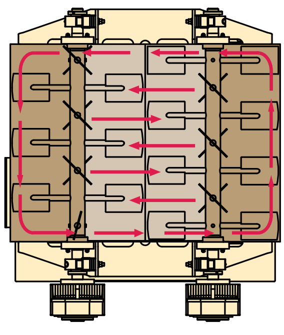


Figure 1 (right, top): In Zone A, fluidization promotes thorough mixing. Figure 2 (right): Material interchange between the two drums

The Bella mixer is available in stainless steel and mild steel construction.

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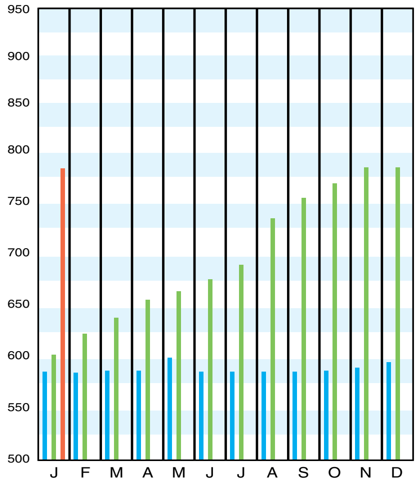


CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Jan. '22 Prelim.	Dec. '21 Final	Jan. '21 Final
CE Index	785.9	776.3	616.5
Equipment	991.6	977.9	751.5
Heat exchangers & tanks	856.8	830.2	637.3
Process machinery	993.2	975.8	746.8
Pipe, valves & fittings	1,453.0	1,414.8	1,012.4
Process instruments	569.2	564.4	439.8
Pumps & compressors	1,233.3	1,179.3	1,103.4
Electrical equipment	700.9	678.0	573.2
Structural supports & misc.	977.5	1059.4	798.7
Construction labor	345.6	347.6	334.6
Buildings	828.1	808.3	635.0
Engineering & supervision	310.7	310.8	311.1

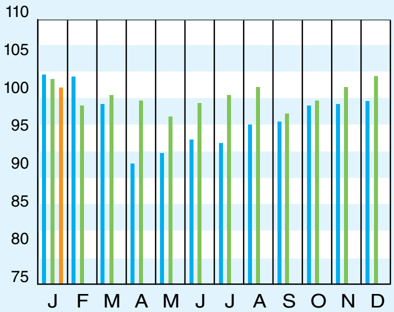
Annual Index:
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2
2021 = 708.0

Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

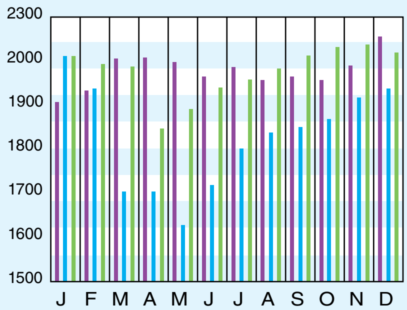
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2017 = 100)	Jan. '22	=	99.6	Dec. '21	=	99.5	Nov. '21	=	99.3	Jan. '21	=	95.2
CPI value of output, $ billions	Dec. '21	=	2,100.2	Nov. '21	=	2,103.8	Oct. '21	=	2,090.2	Dec. '20	=	1,761.8
CPI operating rate, %	Jan. '22	=	79.3	Dec. '21	=	79.3	Nov. '21	=	79.1	Jan. '21	=	75.8
Producer prices, industrial chemicals (1982 = 100)	Jan. '22	=	330.9	Dec. '21	=	335.4	Nov. '21	=	341.2	Jan. '21	=	252.9
Industrial Production in Manufacturing (2017 =100)*	Jan. '22	=	100.7	Dec. '21	=	100.4	Nov. '21	=	100.6	Jan. '21	=	98.2
Hourly earnings index, chemical & allied products (1992 = 100)	Jan. '22	=	191.8	Dec. '21	=	193.9	Nov. '21	=	193.3	Jan. '21	=	193.5
Productivity index, chemicals & allied products (1992 = 100)	Jan. '22	=	94.9	Dec. '21	=	93.9	Nov. '21	=	96.7	Jan. '21	=	90.7

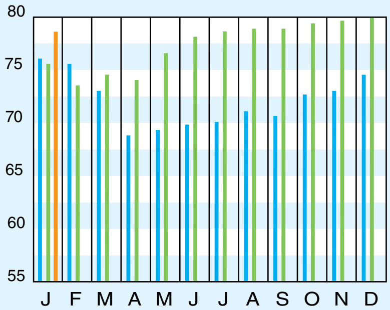
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for January 2022 (most recent available) was higher than the previous month, continuing an upward trend throughout 2021. Gains in the Equipment and Buildings subindices for January offset small decreases in the Construction Labor and Engineering & Supervision subindices. The current CEPCI is now 27.5% higher than the same time a year ago. With the final CEPCI values for 2021 now available, the annual 2021 CEPCI value can be calculated. The 2021 annual CEPCI value is 708.0, an average of the monthly values in 2021.

Editor's note: In the February and March issues, the two-months-previous values in the CBI for the Productivity Index for CBI were reported incorrectly, at 357.0 and 358.0, respectively. The correct values are 93.6 and 94.2.